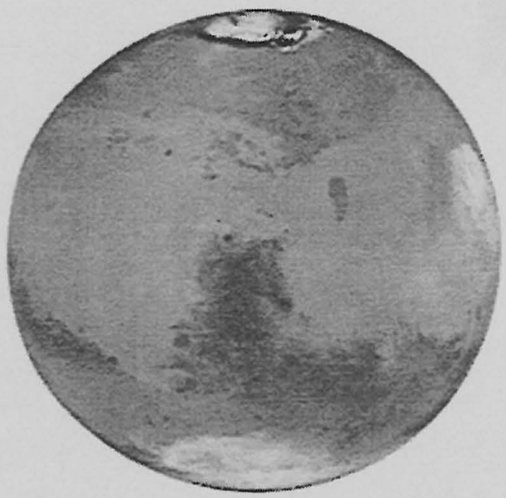
1062

Concepts and Approaches for Mars Exploration

Part 1



Hosted by

Lunar and Planetary Institute

Sponsored by

NASA Headquarters
Lunar and Planetary Institute

CONCEPTS AND APPROACHES FOR MARS EXPLORATION

Part 1

Hosted by

Lunar and Planetary Institute
July 18–20, 2000
Houston, Texas

Sponsored by

NASA Headquarters
Lunar and Planetary Institute

Convener

Scott Hubbard, NASA Headquarters

LPI Contribution No. 1062

Compiled in 2000 by
LUNAR AND PLANETARY INSTITUTE

The Institute is operated by the Universities Space Research Association under Contract No. NASW-4574 with the National Aeronautics and Space Administration.

Abstracts in this volume may be cited as

Author A. B. (2000) Title of abstract. In *Concepts and Approaches for Mars Exploration,* p. xx. LPI Contribution No. 1062, Lunar and Planetary Institute, Houston.

This report is distributed by

ORDER DEPARTMENT
Lunar and Planetary Institute
3600 Bay Area Boulevard
Houston TX 77058-1113
Phone: 281-486-2172
Fax: 281-486-2186
E-mail: order@lpi.usra.edu

Mail order requestors will be invoiced for the cost of shipping and handling.

Preface

This volume contains abstracts that have been accepted for presentation at the Concepts and Approaches for Mars Exploration workshop, July 18–20, 2000.

Logistical, administrative, and publications support were provided by the Publications and Program Services Department of the Lunar and Planetary Institute.

Contents (Part 1)

PHONING HOME FROM MARS IN 2025, J. Adams, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, (e-mail: jta@jpl.nasa.gov).

Introduction: It's spring at Martian Outpost 3, the year 2025. The Universe Cup's on later today, and next week little Suzie celebrates her fourth birthday. Fortunately, this football fan and parent will be able to participate in both of these activities, albeit at a slight time delay, due completely to the sophisticated, high-speed quasi-real-time multimedia/navigation MarsNet surrounding Mars and tying it to Earth. Capable of moving gigabits a second in either direction, the network supports not only the multiple manned and robotic science needs of teams and devices encircling Mars, but also the very real human need for communication.

The Mars Network: This network has its heritage in the earth-encircling telecom/navigation networks first implemented at the beginning of the century: Iridium, Globalstar, Orbcomm, the GPS constellation, to name a few.

Tied with an inseparable link to Earth (except during the two weeks surrounding conjunction and they're working to fix that), the network handles quasi real-time multimedia communications to and from the Earth, and real-time multimedia communications and navigation between the various Martian outposts and robotic and manned exploration teams.

Back on Earth, what used to be the NASA Deep Space Network (DSN) has evolved into a public-utility dedicated Mars-Earth long-distance provider. The DSN pioneered the art of deep-space spacecraft-to-earth communication, and logically served as the basis for early interplanetary planetary and deep-space communications protocols. Protocols, hardware and operations concepts were created and honed in the 1950's, but always remained very single-user-centric. Now, with with multiple ground stations on six continents keeping a high-speed data, timing and nav link operating between the two planets, this new deep-space network provides tremendous connectivity. At any time, there are at least two of these ground stations linked to the areostationary MarsSat Mark IV relay orbiters, a spinoff of the old TDRSS and commercial satellite systems at the turn of the century. These stationary spacecraft provide direct communications and navigation support to Mars surface and orbital assets. In addition, a low-Mars-orbit constellation of smaller, simpler spacecraft augment the areostationary MarSats to provide solid, regular service to the planet's poles and to micropower surface assets.

Enabling Exploration: It was recognized in the first decade of 2000 that the long-view plan for Mars robotic exploration required an orbiting infrastructure of telecommunications/navigations spacecraft. With this in place and responsible for handling the long-haul link between Mars and Earth, the missions arriving at Mars could use far more efficient, low-power, low-mass transceivers with either omni or electronically steered antennas to close the short link from the surface to the orbiters. These kilograms of mass and watts of power saved enabled each mission to do more science and eliminate the majority of operational constraints that the telecom solutions before had imposed.

The original proposers of this network also considered that the infrastructure they created would serve as the basis of what would come next and would only change incrementally due to the difficulties and financial pressures always inherent in Mars exploration, and so they chose to take into account eventual human habitation and needs as a logical customer of their network.

Don't Reinvent the Wheel: The inablility to appreciate and make use of a good, solid design when it wasn't invented here is a dangererous thing. The development of telecommunications started in the 19th century with the first data transfers via telegraphy, to scratchy, tinny voices carried over a copper pair, to a worldwide infrastructure of reliable landline communications, to a nascent but exponentially growing infrastructure of wireless telecommunications. We have the benefit of all the things that have passed. Wireless communications is absolutely the norm now, with strong and robust standards including WCDMA, CDMA2000, advanced TDMA, IEEE 802.11, Bluetooth, etc. Hundreds of billions of dollars have been poured by commercial companies into these standards and equipment and this investment has created a host of multimedia networks that are well-tested and unrivaled by anything that has come before. The standards and the equipment that this investment has fostered can be used anywhere that humans can exist.

Where Do We Go From Here?: Proposed Mars communications standards reflect the philosophies and standards of the 40-year old NASA Deep Space Network. An amazing and fantastically successful system, it was never intended to perform multi-user communications, provide communications between remote users, and certainly was never designed to by symmetric. Adopting and adapting the existing and proposed commercial network/telecommunications standards is not only good business sense, but probably the only way that those videos from home will make it to Mars.

PROPOSED SCIENCE REQUIREMENTS AND ACQUISITION PRIORITIES FOR THE FIRST MARS SAMPLE RETURN. C. B. Agee[1], D. D. Bogard[2], D. S. Draper[2], J. H. Jones[2], C. Meyer Jr.[2], and D. W. Mittlefehldt[3] [1]NASA Johnson Space Center (Mail Code AC, Houston TX 77058, carl.b.agee1@jsc.nasa.gov), [2]NASA Johnson Space Center (Mail Code SN, Houston TX 77058), [3]Lockheed Martin SO, Houston TX.

Introduction: A sample return mission is an important next step in the exploration of Mars. The first sample return should come early in the program timeline because the science derived from earth-based analyses of samples provides crucial "ground truth" needed for further exploration planning, enhancement of remote measurements, and achieving science goals and objectives that include: (1) the search for environments that may support life and any indicators of the past or present existence of life, (2) understanding the history of water and climate on Mars, (3) understanding the evolution of Mars as a planet. Returned samples from Mars will have unique value because they can be studied by scientists worldwide using the most powerful analytical instruments available. Furthermore, returned Mars samples can be preserved for studies by future generations of scientists using new techniques and addressing new issues in Mars science. To ensure a high likelihood of success, the first sample return strategy should be should be simple and focused. Below we outline a fundamental set of sample requirements and acquisition priorities for Mars sample return.

"Zeroth" Level Science Requirements:
Mission success hinges on having clear goals and well-defined requirements. In our opinion there is a single fundamental or "zeroth" level science requirement that defines a successful sample return mission:
0. Return a sample of scientifically relevant size and quality from Mars to Earth and preserve its scientific integrity.

Level 1 Science Requirements:
In order to maximize the science yield of the first Mars sample return we propose additional level 1 requirements:

1. The returned sample should be no less than 1 kilogram of regolith, windblown dust, and small rocks (pebbles) from the surface and subsurface of Mars.
2. The landing site should be scientifically relevant and interesting, with a priority on sites that are significant in understanding the history of water on Mars.
3. Design the process of acquisition, return, and study to maximize information content and minimize sample contamination.

Sample Acquisition Priorities:
Sample return success can be enhanced by employing acquisition techniques that are redundant and/or diverse and proceed from the simpler to the more complex. Against these considerations, an approximate priority list of sample types is given below. How far sample acquisition proceeds down this priority list would be balanced against mission complexity, cost, and reliability.

I. Contingency Sample (mass hundreds of grams):
A near-surface "contingency" sample should be acquired by highly reliable methods very early after landing. This sample would consist of local surface and sub-surface regolith acquired by lander arm and scoop.

II. The Second Priority Sample Type is the acquisition of regolith pebbles (hundreds of grams):
This sample should consist of many cm-sized pebbles, to include both solid rock and friable objects. These might be obtained from the regolith by using a sieve on the sampling arm. Use of a "nutcracker" jaw on the arm might identify pebbles that do not easily break and likely represent solid rock.

III. Contingency Considerations:
The situation might occur that the lander rests on solid rock without regolith. If this is deemed a significant possibility, capability should exist to acquire rock samples or samples some distance away from the lander. Possible mechanisms might include a drill capable of acquiring sample from solid rock, a tethered rover, or some other device. An alternative approach would be to choose a landing site with a very low probability of having extensive rock outcrops.

IV. Other Highly Desirable Sample Types:

1. An atmospheric sample, either contained within the sample return container or hermetically sealed in a separate, dedicated atmospheric container.
2. Sample of subsurface regolith to a depth of 1 meter or more acquired by a drill/coring device. This sampling mechanism might offer extra reliability against failure of the sampling arm.
3. Rock and regolith samples acquired some distance from the lander to ensure sample variety. Mechanisms for such sample collection might include a tethered rover (see III above).

Clean and Cold Sample Curation. C. C. Allen[1], C.B. Agee[2], R. Beer[3], and B. L. Cooper[3], [1]Lockheed Martin Space Operations, 2400 NASA Road 1, Houston, TX 77058, carlton.c.allen1@jsc.nasa.gov; [2]NASA Johnson Space Center, Houston TX 77058, carl.b.agee1@jsc.nasa.gov; [3]Oceaneering Space Systems, 16665 Space Center Blvd., Houston TX 77058, rbeer@oss.oceaneering.com, bcooper@oss.oceaneering.com.

Introduction: Curation of Mars samples includes both samples that are returned to Earth, and samples that are collected, examined, and archived on Mars. Both kinds of curation operations will require careful planning to ensure that the samples are not contaminated by the instruments that are used to collect and contain them. In both cases, sample examination and subdivision must take place in an environment that is organically, inorganically, and biologically clean. Some samples will need to be prepared for analysis under ultra-clean or cryogenic conditions. Inorganic and biological cleanliness are achievable separately by cleanroom and biosafety lab techniques. Organic cleanliness to the <50 ng/cm^2 level requires material control and sorbent removal - techniques being applied in our Class 10 cleanrooms and sample processing gloveboxes.

Samples Returned to Earth: For Martian samples returned to Earth, the terrestrial environment must be protected from possible biosafety hazards related to the sample. Consequently, the sample receiving laboratory must meet the three main objectives required of all biocontainment facilities: 1) protect the laboratory workers, 2) protect the environment (in this case the entire biosphere), and 3) protect the scientific integrity of the samples.

Samples that Remain on Mars: There will be many more samples collected on Mars than will be returned to Earth. During robotic precursor missions, rocks and soils will be examined to determine which are of most interest for return to terrestrial laboratories or for additional remote study. The ability to manipulate these samples and perform basic chemical analyses will allow us to select the most appropriate samples for return to Earth.

After humans have arrived on Mars and have begun to conduct geological traverses, many of the samples that they collect will be examined within a laboratory at the Mars base camp. Compact, intelligent systems will be required that can protect the crew from biohazards while automating many of the tasks of sample preparation and analysis, such as photo-documentation, subsample collection, grain size analysis, recognition of anomalies, etc.

Robotic Sample Preparation: We are testing the utility of highly dexterous, non-contaminating robots in controlled-atmosphere gloveboxes, using a precision robotic/teleoperated system that was originally developed by Oceaneering Space Systems for International Space Station payloads.

A controlled-environment glovebox with a robotic micromanipulator could be useful for processing samples that are returned to Earth, as well as for samples that remain on Mars. The technology includes precision robotics and tooling; environmentally-controlled gloveboxes and workspaces (including cryogenic cooling as needed); and video and data telemetry for command and control of curation operations as well as sample analysis. Moreover, the general architecture and system is already designed for space flight.

The glovebox/telescience facility is designed to withstand launch loads, and is compact enough to fit within standard spacecraft accommodations. It is also designed to operate with a minimum of human intervention. It allows precise and accurate manipulation of the contents within the glovebox via preprogrammed robotic command sequences or via teleoperation. For an additional level of redundancy, it can also be operated directly by a crew member using the traditional glovebox gloves. Figure 1 shows the front face of the technology demonstrator unit for the version of the box that is planned for the International Space Station's X-Ray Crystallography Facility.

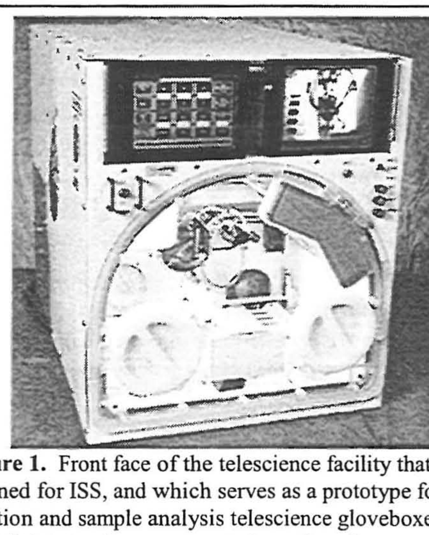


Figure 1. Front face of the telescience facility that is planned for ISS, and which serves as a prototype for curation and sample analysis telescience gloveboxes. At top left is a touch screen control panel, and at top right is a video monitor for imaging system camera and microscope views. Viewing window, resupply port, and glove ports are also visible (figure courtesy of Oceaneering Space Systems).

IPSE: ITALIAN PACKAGE FOR SCIENTIFIC EXPERIMENTS. F. Angrilli[1], E. Flamini[2], and S. Espinasse[2], [1]CISAS University of Padova, Via Venezia, 1 35131 Padova – Italy, [2]ASI Viale Liegi, 16 00198 Roma – Italy

IPSE is a scientific autonomous micro-laboratory for Mars soil and environment analysis. It was proposed for the previous 2003 Mars Sample Return mission and more generally speaking for the Mars Exploration Program. It provides the capability to serve, handle and manage scientific miniaturized instruments accommodated inside its envelope. These instruments will carry out scientific measurements on soil samples, atmosphere, radiation environment and dust flux.

The first version, now under development, will have basic capabilities and no mobility but the philosophy of the design is to have a modular system that will evolve with each launch opportunity. Its general configuration for the 2003 MSR mission is based on a structure with an external envelope to fit the available room on the Lander deck and featuring 10 kg mass, inclusive of four scientific instruments described hereafter. A small robotic arm with 3 or 4 degrees of freedom is normally stowed inside the IPSE envelope and provides, during operations, the capability of delivering soil samples to the instruments taken from the deep soil drill (DEEDRI).

IPSE is designed to operate in Martian environmental conditions but it could be adapted for other purposes. This means that it will be able to operate at low temperatures and low pressures in a sandy and windy atmosphere.

The IPSE structure will contain power conditioning for the various users, and electronics for system and thermal control, and communications and instrument data handling. IPSE is equipped with a processing unit, allowing for a high degree of operational autonomy and flexibility in the operational sessions. A modularity philosophy has been implemented to allow the maximum level of de-coupling between IPSE and the experiments. It will feature the following main capabilities:

- Autonomous thermal control.
- Electrical interface with the Lander to provide and manage power supply to all IPSE subsystems and to the scientific payload.
- Communication interface with the Lander to receive high level commands, telecommands from ground and to transmit the collected scientific data, housekeeping and status parameters.
- Control of the robotic arm for sample handling, sample collection from the drill, sample delivery and discharge to scientific instruments.
- Sample preparation prior to analysis. In case of dusty or soft soil samples, the sample will be slightly compressed prior to measurement to reduce it to a proper layer. This preliminary operation provides a way to evaluate correctly the proper sample position underneath the instruments for optimal focusing.
- Control of the micromechanisms for sample motions parallel (bi-directional micrometric linear motion) and normal to the focal plane for optimal focusing and execution of two dimensional spectral analysis.
- Processing capabilities, including housekeeping functions, scientific measurements scheduling and instruments power on/off, data acquisition, compression, temporary storage and transmission to the Lander.

The scientific experiments integrated in IPSE are:

- **IRMA** (InfraRed Microscope Analysis), a microscope and imaging spectrometer designed to obtain images and reflectance spectra of samples in the 0.8-5 μm spectral region. Since IR spectroscopy in the range 0.8-4.0 μm can be used to determine the abundance of many types of minerals including clay hydrates and carbonates it will carry out a detailed mineralogical analysis of the martian soil.

- **DOSE** (DOSimeter Experiment) is an experiment for monitoring the β and the γ radioactivity during the cruise phase and at the surface of Mars, in the range 30-300 KeV. It consists of lithium-fluoride doped pills which can be exposed to the radiation, reset and readout by heating the pills within a oven to a temperature of about 300°C. The events absorbed in the pill cause a thermoluminescent process during heating cycle and the emission of an optical signal flux proportional to the absorbed dose.

- **MA_FLUX** (MArs X FLUorescent Experiment) will investigate the Martian surface using the X-ray fluorescence technique, thus allowing the detection of chemical trace elements in the Martian soil, down to a few ppm. This instrument investigates the interior of samples to a depth ranging between one mm and one cm. Furthermore it defines precisely the X-ray absorption capacity of samples and permits the estimation of the abundance of elements heavier than iron. It is based on a detector that utilizes a new CdTe hard X-ray detector coupled with multiple gamma ray sources to increase the energy resolution.

- **MAGO** (Martian Atmospheric Grain Observer) measures cumulative dust mass flux and dynamical properties of single intercepted particles as a function of time. It will allow determination of grain mass, size and shape distribution, and dynamic behavior of airborne dust. It is a single instrument including three different detection subsystems (three micro-balances using quartz crystals as detectors of mass deposition, a grain detection system based on the detection of the scattered/reflected light produced by the passage of single grains through a collimated laser light "curtain", and an impact sensor (piezoelectric sensor) for the detection of the momentum released during the impact of single grains on a sensing aluminum plate.

In addition to the listed payloads, the possibility to interface and serve an additional P/L called MOD (Mars Organic Detector), designed for in-situ detection of organic compounds directly on the surface of Mars has been considered as an option. MOD will be positioned in the Lander close to IPSE and it will receive from IPSE power and data interface with the Lander and the samples to be analyzed.

VISION 2020: A PROPOSED PROGRAM OF MARS EXPLORATION. R. E. Arvidson, Department of Earth and Planetary Sciences, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, arvidson@wunder.wustl.edu, Tel: 314 935 5609, Fax: 314 935 4998

During the joint Mars Exploration Program and Analysis Group / Mars Architecture Review Group session in February 2000, the Resources Sub-group met and generated a 20-year plan for Mars exploration. The plan focused on meeting the following goals by the year 2020:

• Determine stratigraphic and structural nature of major crustal units and their spatial/temporal evolution and implications for the generation and preservation of organic and biologic materials.

• Determine nature and timing of the internal dynamo and resultant magnetic field, including impact on surface habitats associated with field demise.

• Determine nature, extent, and accessibility of water reservoirs on a global scale and implications for the origin and evolution of life.

• Demonstrate and employ resource utilization technologies to enable missions and mission activities, focusing on *in-situ* fuel generation from atmosphere and water reservoirs.

To meet the goals the following specific objectives were defined for the current decade, an era that might be termed The Decade of Surface Exploration:

• Characterize major crustal units in detail through orbiting missions (MGS Extended Mission, Mars 2001 Orbiter with THEMIS and GRS/HEND, Mars Express), *in-situ* observations (Mars 2003 rover, Beagle Lander), and collection and initial analyses of returned samples.

• Add to the existing and planned measurements high spatial resolution (30 to 100 m/pixel) IR imaging spectroscopy of key terrains selectable on a global basis because of the importance for rock and soil characterization and resource inventory.

• Continue characterization of interior structure and dynamics (MGS Extended Mission, Net-landers, other orbiters).

• Conduct demonstrations of extraction and utilization of key resources on landers.

For the period from 2010 to 2020, The Decade of Subsurface Exploration, the following specific objectives were identified:

• Determine remanent magnetic crustal fields globally at high spatial resolution from orbiter. When combined with crustal history, structure and dynamics of interior, infer nature and timing of dynamo and internal field and implications for surface habitats.

• Characterize shallow subsurface regolith/crustal structure, stratigraphy, and resources globally, including accessible water reservoirs using geophysical techniques from orbit, air, and surface.

• Determine nature, depth, and extent of water reservoirs in detail for key sites using *in-situ* geophysical surveys.

• Continue surface sample returns. First returns only begin the process of characterizing the diverse geology, climate history, and implications for life on Mars.

• Continue experiments in extraction and utilization of key resources, focusing on *in-situ* fuel generation from atmosphere and water reservoirs. Ensure that experiments support implementation of architecture.

• Drill to aquifer in at least one site, acquire samples of water, ice, rock, measure properties and return subset of samples to Earth.

These ideas may serve as a focus for discussion at the workshop and a basis for the addition and/or reprioritization of objectives, based on the incorporation of additional discipline-oriented perspectives such as climatology.

FIDO FIELD TRIALS IN PREPARATION FOR MARS ROVER EXPLORATION AND DISCOVERY AND SAMPLE RETURN MISSIONS. R. E. Arvidson[1], E. T. Baumgartner[2], P. Schenker[2], S. W. Squyres[3], [1]Department of Earth and Planetary Sciences, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, arvidson@wunder.wustl.edu, Tel: 314 935 5609, Fax: 314 935 4998, [2]Jet Propulsion Laboratory, Pasadena, CA 91109, [3]Department of Astronomy, Cornell University, Ithaca, NY 14853-6801

The Mars 2003 Mission may include a rover to acquire remote sensing and *in-situ* measurements of surface materials, including rock surfaces that have been cleared of dust and coatings by use of an abrasion tool. Mars Sample Return Missions for 2005 and beyond may include rovers with remote sensing and in-situ measurement capabilities. Further, these mobility platforms may have systems to drill into rocks and collect cores, acquire soil samples, and place the rock and soil samples in ascent vehicles. The point of this abstract is to document that these operations have already been shown to be tractable based on continuing field trials of the FIDO Mars prototype rover.

The Field Integrated Design and Operations (FIDO) Rover [1] simulates mobility-based exploration, discovery, and sampling activities, with a science payload similar to the Athena Payload originally selected for the 2003/2005 Mars Sample Return Rovers [2,3]. In its initial field trials, FIDO was deployed and controlled remotely for two weeks in 1999 in the Silver Lake area, Mojave Desert, California [3] and in 2000 near the Lunar Crater Volcanic Field in Nevada. FIDO successfully completed traverses of over 600 m in diverse terrain while acquiring imaging and spectral reflectance data. FIDO also successfully identified, maneuvered to, and cored into rocks. The trials validated the mission operations approach for long distance roving and for collecting samples. The trials also provided numerous lessons that will maximize the science return associated with rover-based observations and sampling activities.

During the Silver Lake trial, FIDO was commanded in the field through a wireless Ethernet connection from a command trailer using the Web Interface for Telescience (WITS) rover operations software system [4]. Data obtained by FIDO were transmitted through this system back to the command trailer. The command trailer also included a satellite link capability, allowing remote science team personnel to participate using the Internet. For the Lunar Crater tests, the Core Operations Team (COT) was located at the Jet Propulsion Laboratory and all command sequences were generated using WITS at JPL and then uplinked to the rover. All downlink telemetry products were also processed at JPL. Orbital and simulated descent data were provided to the COT in order to generate initial hypotheses regarding the field site. The scientific instrument suite located on the rover was then used to test these hypotheses. In both field trials, two phases of rover missions were simulated. The first focused on finding and sampling rocks, using panoramas acquired from the initial rover positions on simulated landers as vantage points. Targets were then selected and waypoints defined in range coordinates for the traverses to the targets. The rover then autonomously traversed through the waypoints using on-board hazard detection and avoidance software. Once FIDO reached within 1 to 2 m of a target, Pancam (false color IR) and Navcam image data and Infrared Point Spectrometer spectra (1.4 to 2.5 micrometers) were acquired to identify and/or confirm target mineralogy and to plan the detailed movements needed to place the Mini-Corer over the designated rocks. The rover was then commanded to a position directly above a rock, the rock was cored, and the microscopic imager was used to verify core acquisition. During the 1999 tests an arm-based color microscopic imager and Mössbauer Spectrometer were also placed against the rock targets and data were acquired. Radiation safety issues required that the Mössbauer data be acquired in the trailer overnight by transporting the rocks to and from the field. All of these activities were commanded remotely from the command trailer, using only rover-generated data for guidance. Similar activities were successfully implemented during the Lunar Crater tests, except that the Mössbauer Spectrometer was not include because of radiation safety issues.

The exploration and discovery portion of the field trials consisted of traverses along the alluvial fan and down the breakout channel for the 1999 test and traverses along an alluvial fan for the Lunar Crater tests. FIDO traversed approximately 600 m and acquired Pancam and IPS data to characterize terrain, soils, and rocks at predefined points along the traverses. For example, during the breakout channel traverse in 1999, imaging and spectra were used together to delineate the proportions of dolomite and calcite in cemented alluvium exposed on a boulder from the upper channel wall. The exploration and discovery portion of the field trial was extended during both tests by high school students who remotely planned traverses and drove the rover during the exploration and discovery portion of the mission as part of a nation-wide education and outreach experiment called LAPIS [5].

The first major lesson from the rover trials is that with careful planning and implementation, it is possible to accomplish remote identification of targets, waypoint selection and traversing, coring, and documentation of core presence. Secondly, use of overhead imaging and emission spectra to develop hypotheses, coupled with acquisition and analysis of rover-based image and spectral data to test ideas and select targets for sampling, was found to be a powerful combination for maximizing scientific returns from rover operations. This approach will allow us to place rover-based remote sensing data and *in-situ* observations in a broader framework of observations and hypotheses. In addition, the rover-based observations will allow analyses derived from the samples in Earth-based laboratories to be placed in a broader context or geologic framework.

The trials also demonstrated that the exploration and discovery portion of the rover mission, with remote sensing and *in-situ* observations, will lead to significant and exciting field-based observations that cannot be replicated in other ways. For example, it is quite possible that the reason carbonates have not been observed spectrally on Mars from orbit or Earth is that these deposits are disseminated in low concentrations throughout the upper crust. This hypothesis is certainly consistent with the fracture-filling nature of the carbonates in the Martian meteorite Alan Hills 84001 [6]. Identification of carbonates and other aqueous minerals filling fractures on Mars can be done *in-situ* using the Athena Payload.

Real-time documentation of events is another key lesson learned, in that planning and implementation of the field work went so quickly that it was easy to forget why certain data sets were acquired. This lesson led to the concept of an Experimenter's Notebook (http://wufs.wustl.edu/rover), with easy-to-use templates to be filled in by a documentarian during the mission. Numerous other lessons were learned from the field trials that relate to such areas as hazard avoidance techniques, the need for enhanced visualization software to portray the scene, rover, and articulated elements, and efficient operation of the science and rover command teams. FIDO field trials are planned for at least the next two years, becoming more and more flight-like in planning and implementation. These trials will maximize the scientific utility of operations on Mars, both because lessons from the trials will be used to improve operational procedures and tools, and because the relevant Core Operations Teams will have been through several rover missions before the actual missions take place on Mars.

References:

[1] Schenker, P. S, et al., (1999) SPIE Proceedings 3837. [2] Squyres, S. W., (1998) Lunar and Planetary Science Conference XXIX. [3] Arvidson, R. E., et al., (2000), *EOS*, 81, 65-72. [4] Backes, P.G., et al., (1997) *Proc. IEEE Int. Conf. Robotics Automat., LXIII,* 411-417. [5] Arvidson, R. E., et al. (2000) *EOS,* 81, 113-117. [6] McKay, D. et al., (1996) *Science,* 273 (5277), 924-930.

MOD: an Instrument for the 2005 Mars Explorer Program HEDS Payload

Principal Investigator: J. L. Bada, Scripps Institution of Oceanography, UC San Diego, La Jolla, CA 92093: email-jbada@ucsd.edu
Co-Investigators: D. L. Blaney, F. J. Grunthaner, G. D. McDonald, C. R. Webster, NASA JPL, Pasadena, CA; M. Duke, LPI, Houston TX; R. A. Mathies, UC, Berkeley, CA; C. P. McKay, NASA AMES, Moffet Field, CA; D. A. Paige, UCLA, Los Angeles, CA; S. K. Ride, UC San Diego, La Jolla, CA; M. Wadhwa, Field Museum, Chicago, IL

The Mars Organic Detector (MOD) was recently selected for the definition phase of the HEDS '05 (originally scheduled for '03) lander instrument package for fundamental biology and *in situ* resource utilization. MOD is designed to detect organic compounds in rock and soil samples directly on the surface of Mars in order to assess the biological potential of the planet. In addition, a MOD Tunable Diode Laser Spectrometer (TDLS) will provide information on desorption and decomposition temperatures, as well as the release rates and quantities of water and carbon dioxide that can be liberated from regolith samples, thereby providing the parameters needed for the design of systems for the future large-scale *in situ* extraction of valuable consumable resources. A MOD TDLS will also measure the atmospheric water and carbon dioxide content, as well as the atmospheric carbon dioxide isotopic composition, in order to determine whether there is an isotopic offset between atmospheric and surface carbon.

MOD is a mature instrument concept with an extensive heritage. MOD evolved from projects funded under the Planetary Instrument Definition and Development Program (PIDDP) and the Mars Instrument Development Program (MIDP). A MOD spacecraft instrument design has undergone two design iterations and a prototype is now being tested. The TDLS component of MOD is an enhanced version of the Evolved Gas Analyzer in the Mars Volatiles and Climate Surveyor (MVACS), which was lost with the failure of the Mars Polar Lander (MPL). MOD is designed to sample the 2005 landing site using acquisition devices such as the Deep Drill System (DEEDRI) provided by the Agenzia Spaziale Italiana (ASI) or a scoop similar to the one on MPL.

The analyses to be carried out by the MOD are designed to examine three important hypotheses relevant to fundamental biology and in situ resources:

1) Organic compounds associated with either extinct or extant life and/or abiotic chemistry are present in Martian regolith samples.
2) Extractable water and carbon dioxide, in amounts needed by future human explorers, can be obtained from the Martian regolith.
3) Carbon dioxide in the Martian atmosphere is depleted in the isotope carbon-13 relative to that in surface carbonates.

To test first the two hypotheses, MOD carries out two simultaneous, complementary experiments: simple sublimation-based extraction, fluorescence detection and quantification of the key organic compounds amino acids, amines, and polycyclic aromatic hydrocarbons (PAHs) at sub-picomole ($<10^{-12}$ mole) levels—that is, at least 100 times more sensitive then Viking—and the tunable diode laser spectrometer (TDLS) detection and quantification of evolved water and carbon dioxide in order to assess the water and carbonate inventory of the Martian surface. The last hypothesis is tested by direct measurements of the atmospheric carbon dioxide content and its isotopic composition using a TDLS.

The MOD instrument (see **Figure 1**) consists of a delivery arm and a rock crusher; an organic detector, consisting of a sublimation cell, a chemical detector, and a fluorescence analyzer; and two TDLSs, which each have a Herriott cell, a dual laser system, and a miniature capacitance manometer and Pirani gauge to measure absolute pressure.

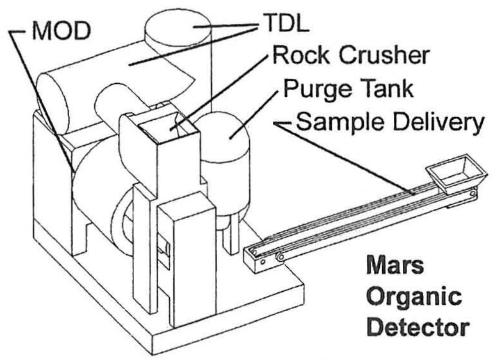


Figure 1: The MOD 2005 instrument showing the various components. The entire instrument weighs ~2 kg and fits in the palm of your hand. Peak power requirements are around 28 watts. The purge tank is used to flush the MOD oven and attached TDLS with an inert gas such as argon between analyses.

During the operational sequence (**Figure 2**), the sample delivery arm first receives a sample which is then dropped it into the rock crusher where it pulverized before being transferred to the MOD oven for analyses. After closing the oven at Mars ambient pressure, the crushed sample will be stepwise heated to 950°C. Amino acids and PAHs in the sample will be sublimed and collected on a cold finger (located at the rear end of the oven) which is cooled to Mars night time temperatures (around -100°C). This sublimation based method has previously been demonstrated to efficiently extract amino acids, amines and PAHs from various types of terrestrial samples and meteorites {Glavin, D. P. & Bada, J. L. (1998) ***Anal. Chem.* 70**, 3119-3122)}. The MOD cold finger is divided into two zones: one is coated with fluorescamine which reacts with amino acids and other primary amines to generate an intense fluorescent derivative; the other is uncoated and is used to directly detect PAHs, which do not require a reagent in order to produce an intense UV fluorescent signal. The sublimed compounds are detected by using laser-based fluorescence sensors.

During the same heating sequence used to sublime the target organic compounds, bound water, along with carbon dioxide produced from the decomposition of various carbonate minerals, will be released from the samples. The quantities of water and carbon dioxide, and their isotopic compositions, evolved are determined using a TDLS directly connected to the MOD oven. A second TDLS with an open-path sample cell will measure the water and carbon dioxide content and carbon dioxide isotopic composition of the Martian atmosphere at the landing site. On Earth, atmospheric carbon dioxide is depleted in the isotope carbon-13 relative to surface carbonates because of the presence of a large surface reservoir of reduced biologically derived organic carbon. Finding a similar offset between atmospheric carbon dioxide and regolith carbonates on Mars would provide indirect evidence for the existence of a similar reduced organic carbon reservoir, a finding that could be indicative of either past or present Martian biology.

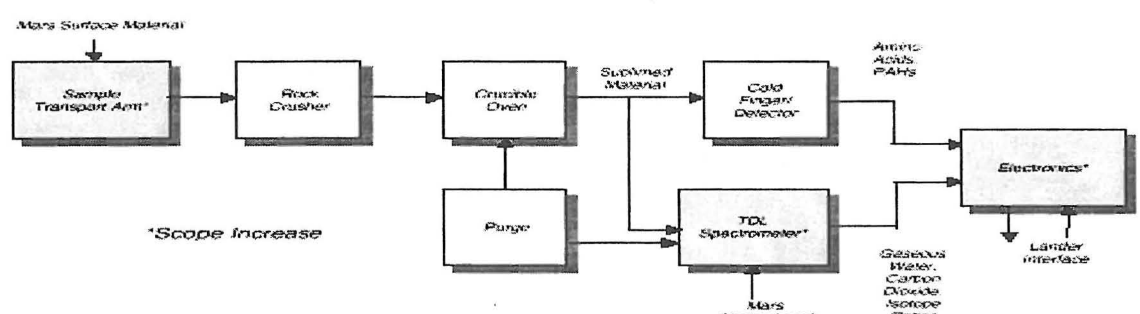


Figure 2: The MOD operational sequence.

A NETWORK MISSION: COMPLETING THE SCIENTIFIC FOUNDATION FOR THE EXPLORATION OF MARS. W. B. Banerdt, Jet Propulsion Laboratory (M.S. 183-501, Pasadena, CA 91109, bruce.banerdt@jpl.nasa.gov).

Introduction: Despite recent setbacks and vacillations in the Mars Surveyor Program, in many respects the exploration of Mars has historically followed a relatively logical path. Early fly-bys provided brief glimpses of the planet and paved the way for the initial orbital reconnaissance of Mariner 9. The Viking orbiters completed the initial survey, while the Viking landers provided our first close-up look at the surface. Essentially, Mars Pathfinder served a similar role, giving a brief look at another place on the surface. And finally, Mars Global Surveyor (and the upcoming orbital mission in 2001) are taking the next step in providing in-depth, global observations of many of the fundamental characteristics of the planet, as well as selected high-resolution views of the surface.

With this last step we are well on our way to acquiring the global scientific context that is necessary both for understanding Mars in general, its origin and evolution, and for use as a basis to plan and execute the next level of focused investigations. However, even with the successful completion of these missions this context will be incomplete. Whereas we now know a great deal about the surface of Mars in a global sense, we know very little about its interior, even at depths of only a meter or so. Also, as most of this information has been acquire by remote sensing, we still lack much of the bridging knowledge between the global view and the processes and character of the surface environments themselves. Thus, in many ways we lack sufficient fundamental understanding to intelligently cast the critical investigations into important questions of the origins and evolution of Mars in general, and in particular, life.

The next step in building our understanding of Mars has been identified by several previous groups who were charged with creating a strategy for Mars exploration (e.g., COMPLEX, MarSWG, Planetary Roadmap Team). This is a so-called "network" mission, which places a large number of science platforms simultaneously on the surface.

Network and Multi-Site Science: A network mission addresses two crucial types of goals. First, the simultaneity of measurements at many locations allows investigations of the interior using seismic, geodetic, and electromagnetic methods. Similarly, it allows studies of the circulation of the atmosphere that can only be done with a globally-distributed set of surface meteorological stations. Investigations which require this type of dispersed, simultaneous measurements are can be classified as network science.

Second, the geologic diversity of the that has been identified by remote sensing needs to be examined and explored on the surface. This is necessary both for providing ground-truth for interpreting the remote sensing observations and for discovering and understanding the physical processes that are active on the surface. If Mars were a homogeneous world, a handful of surface platforms would be sufficient to characterize it. However our exploration to now has served to emphasize just how diverse Mars is, and it is folly to assume that we can "know" the planet by analyzing one or two sites. Thus, we are led to conclude that "multi-site" science, in which similar reconnaissance investigations are attempted at a wide range of places on the surface, is crucial for the scientific foundation that we must build in order to significantly advance the exploration of Mars.

Mission Requirements: Although the detailed design of a network mission (including the specific payload) is well beyond the scope of this contribution, there are a few basic requirements that can be articulated. First, there must be a large number of landers. Although the definition of "large" is clearly subjective, many groups have looked at this subject and have consistently arrived at minimum numbers around 8-12, with preferred numbers ranging from 12-24. These numbers follow both from the network science requirements and from analyses of the diversity of the surface (number of basic geological units, etc.). *This implicitly requires that the landers be relatively simple and inexpensive*. These landers cannot be asked to do everything. A minimum set of measurements that are required to characterize a place on Mars must be developed, with the understanding that detailed in-situ and sample return investigations (which will certainly be driven by the information gathered by the network landers) will be required to address many of the most important problems.

Second, *the platforms must be long-lived.* This is not a requirement for multi-site science, but a common thread among all network experiments is a requirement to accumulate data over a considerable period of time. Without the ability to operate for periods commensurate with a seasonal cycle, network investigation are not viable.

Other requirements, such as targeting precision downlink data rate, and specific instrument should be decided by a broadly-based science and technical team.

Network Missions: Two missions which are currently in the design phase have many of the characteristics required of a network mission. The Netlander mission has been designed specifically to address both the network and multi-site goals (although the network science is given priority). This is a very capable mission, including seismic, meteorological, imaging, electromagnetic, and geodetic investigations on four long-lived landers. It should provide much of the basic information required from a network mission. Its primary drawbacks are: 1) the limited number of landers, and 2) a lack of instrumentation to characterized the site (e.g., mineralogy). Any augmentation in the number of landers for this mission would significantly increase its value.

The second promising development is the so-called Scout. The driving requirement behind its design was a desire for a vehicle that could be built and flown in large quantities. This was basically an attempt to address the multi-site types of requirements. The fundamental problem of the Scout is that there was no commitment made to any requirement for a lifetime of more than a week or so. In order for this to be a viable vehicle for a scientifically justifiable network mission, the issue of lifetime will have to be addressed.

There are, of course, many other possible ways to design a network lander, ranging from a Pathfinder-like system, to a legged lander, to a Mars Microprobe type of concept. Again, the design should be developed to optimize the network and multi-site science goals

Conclusion: The next logical step in the exploration of Mars is a network mission to characterize the last truly unknown frontier on Mars, the interior, and to characterize, on the surface, the geologic diversity of the planet. This knowledge is crucial, and should be required before progressing to in-situ landers with lateral and/or subsurface mobility, sample returns, and ultimately a human presence on Mars.

"FOLLOWING THE WATER" ON MARS: WHERE IS IT, HOW MUCH IS THERE, AND HOW CAN WE ACCESS IT?

N. G. Barlow, Dept. Physics, University of Central Florida, Orlando, FL 32816 ngb@physics.ucf.edu.

Introduction: Analysis of Mariner, Viking, Mars Pathfinder, and Mars Global Surveyor (MGS) data have revealed that water has played an important role in the evolution of Mars. Although the planet is cold and dry today, increasing evidence points to warmer and wetter episodes in the past, perhaps to be repeated in the future. Although the evidence from the valley network and outflow channels has been recognized since Mariner 9, it has been the analysis of Viking and MGS data which have revealed such features as probable paleolacustrine deposits [1], possible paleoshorelines [2], and abundant evidence for large standing bodies of water in the northern plains [3, 4].

Much of the water which appears to have existed on the planet is likely still there. The challenge still facing us is to identify where those water/ice reservoirs are located, determining how much water is available in these reservoirs, and devising strategies by which future astronauts to Mars can obtain it for their use.

Where Is The Water and How Much is There?: Three main sources of H_2O are recognized for present-day Mars. The thin Martian atmosphere is typically saturated with water vapor, although it comprises only 0.03% of the atmosphere. The amount varies seasonally between about 1 and 2 x 10^{15} g, equivalent to a total volume of about 1 to 2 km^3 of H_2O [5]. The white clouds and fog are visible manifestations of the atmospheric water vapor [6].

The remnant north polar cap is believed to be composed primarily of H_2O ice, based mainly on near-IR spectral observations [5]. Models suggest that the cap contains >20 pr μm of water mixed with CO_2 ice. How much water is contained in the south polar cap is more problematic since CO_2 frost usually covers the cap even at the height of summer. The layered deposits surrounding the north and south poles also likely contain vast stores of CO_2-H_2O mixtures.

The advantages of looking for water in the atmosphere and polar regions is that these regions are fairly accessible. The disadvantage is that these reservoirs likely account for only a small amount of the total water available on the planet.

The largest store of water on Mars is probably in the near-surface region. There is abundant geologic evidence that vast stores of H_2O are contained in the martian substrate. The outflow channels and valley networks are the most obvious of the geologic features suggesting the presence of ground water. However, these features are localized in specific regions of the planet and do not provide information about the global distribution of subsurface H_2O.

The most wide-spread indicators of subsurface volatiles are the impact crater ejecta morphologies. The layered appearance of the majority of fresh ejecta morphologies has been interpreted to result from impact into subsurface volatiles [7, 8, 9, 10]. Barlow and Bradley [8] and Barlow [11] argue that variations in the types of layered ejecta morphologies result from impact into target material with varying concentrations and/or physical states of H_2O. Costard [9] and Kuzmin [10] have measured the regional changes in onset diameters for craters with specific ejecta morphologies, resulting in maps of the depths to the volatile-rich layers. Those studies have found that ice is located <200 m below the surface at high latitudes (generally poleward of about 30° latitude) and at depths of about 200 to 500 m in the equatorial region. Koroshetz and Barlow [12] have used a similar technique to identify a near-surface ice reservoir (<200 m) in the Solis Planum region, south of Valles Marineris (Figure 1). Unfortunately, the amount of H_2O contained in these reservoirs is very uncertain since such estimates depend on a number of parameters (i.e., the volatile-to-rock ratio needed to produce the layered morphologies, porosity, etc.) which are poorly constrained at the present time.

Terrain softening is another indicator that ice is present in the substrate, particularly at high latitudes [13]. Terrain softening is the rounding of sharp edges (such as crater rims) and shallowing of crater floors due to creep-related relaxation of ice-rich terrains. The geologic observations of small onset diameters for layered ejecta morphology craters and abundant terrain softening at high latitudes on Mars is consistent with the geothermal models for the distribution of near-surface water and ice [14, 15].

Study of impact crater ejecta morphologies and terrain softened features provide constraints on the distribution of subsurface water and ice, but are only indirect methods for determining the locations of these reservoirs. Since H_2O has played a major role in the history of the planet and will be of great importance to future human explorers and settlers of Mars, direct measurements are needed to verify the locations of these subsurface H_2O reservoirs and obtain better constraints on the amount of water/ice available. Sounding radar, such as the MARSIS experiment on the Mars Express mission [16], can provide important information from orbit. Among the types of experiments which can provide needed data about subsurface volatile reservoirs from surface sites are soil electrical conductivity experiments, seismic profiling, and of course drilling.

How Can We Access the Water?: Water is a particularly valuable resource for human exploration and settlement missions to Mars. Research is ongoing with regard to how to extract useable water from the atmosphere. Determining how pure the water in the polar ice caps might be and how to transport the water over the probable large distances between the caps and human habitats are issues which still need to be addressed. Once the direct experiments outlined above provide information on the depth and concentrations of water/ice in the Martian substrate, methods to extract this water can be discussed in more detail than is currently possible. The primary focus of the upcoming Mars missions should be to address these questions of where the water is, how much is located in the different reservoirs, and how can the water stored in these reservoirs best be accessed.

References: [1] Cabrol N. A. and E. A. Grin (1999), *Icarus, 142*, 160-172. [2] Parker T. J. et al. (1993), *JGR, 98*, 11061-11078. [3] Baker V. R. et al. (1991), *Nature, 352*, 589-594. [4] Head J. W. et al. (1998), GRL, 25, 4401-4404. [5] Jakosky B. M. and R. M. Haberle (1992), in *Mars*, Univ. AZ Press, 969-1016. [6] Smith P. H. et al. (1997), *Science, 278*, 1758-1765. [7]Carr M. H. et al. (1977), *JGR, 82*, 4055-4065. [8] Barlow N. G. and T. L. Bradley (1990), *Icarus, 87*, 156-179. [9] Costard F. M. (1989), *Earth Moon Planet., 45*, 265-290. [10] Kuzmin R. O. et al. (1988), *Solar System Res., 22*, 121-133. [11] Barlow N. G. (1994), *JGR, 99*, 10927-10935. [12] Koroshetz J. and N. G. Barlow (1998), *LPSC XXIX*, Abstract #1390. [13] Squyres S. W. and M. H. Carr (1986), *Science, 231*, 249-252. [14] Fanale F. P. (1976), *Icarus, 28*, 179-202. [15] Clifford S. M. (1993), *JGR, 98*, 10973-11016. [16] Plaut J. J. (1999), *LPSC XXX*, Abstract # 1136.

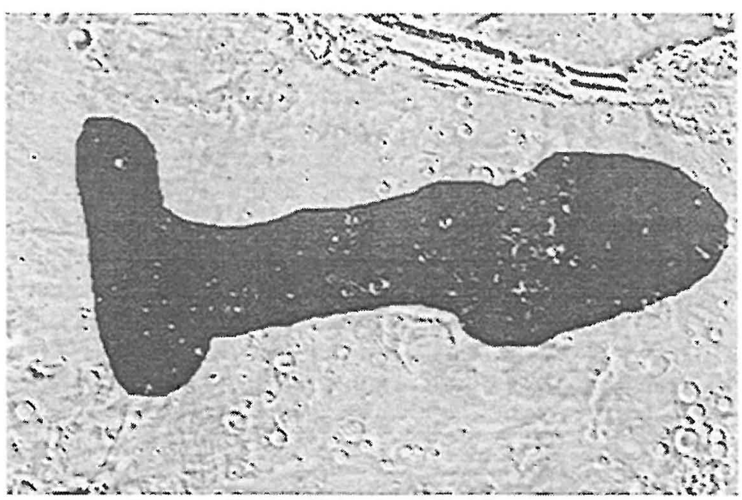


Figure 1. Map outlining the area (in black) in the Solis Planum region south of Valles Marineris where Koroshetz and Barlow [12] have identified a near-surface ice reservoir, based on the small onset diameters for single layer ejecta morphology craters. The reservoir lies between 20°S to 30°S, 50°W to 90°W. Depth to the reservoir is estimated at 200 m or less.

STRATEGIC PLANNING FOR EXPLORATION OF THE MARTIAN SUBSURFACE. D.W. Beaty[1] and G. Briggs[2], S. M. Clifford[3], [1]David.Beaty@jpl.nasa.gov, JPL, 4800 Oak Grove Dr., M/S 264-426, Pasadena, CA 91109, [2]gbriggs@mail.arc.nasa.gov, NASA Ames Research Center, Code 239-20, Moffett Field, CA 94035, [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058, clifford@lpi.usra.edu.

Introduction: Exploration of the upper 2-5 km of the martian crust (i.e. the portion that we can realistically envision physically accessing) is a tantalizing prospect. This may provide our best opportunity to advance the three current objectives of the Mars exploration program: Life, Climate, and Resources, with a common theme of water.

Objectives: Mars subsurface exploration has three objectives: the search for life, acquisition of water as an in-situ resource to support future human and robotic exploration, and understanding the planet's subsurface geology and hydrology (which in turn may provide critical clues regarding its hydrologic and climatic evolution).

The search for life can be advanced at several different scales. First of all, it would be useful to make measurements of the organic carbon content of material collected below the zone influenced by martian surface oxidants. This may be as shallow as a few meters or as great as a kilometer in depth. Second, water-lain sediments -- and perhaps even the frozen relic of an early ocean -- may be present beneath surficial deposits of dust and volcanics present in the northern plains [1]. Such materials, which may exist at depths ranging from several meters to several hundreds of meters, may hold the best chance of preserving a record of extinct life. Third, drilling to access subpermafrost ground water (which may reside from 2-5 km beneath the surface) offers one of the best chances of discovering extant life.

Geophysics: Geophysical investigations are critical to exploring the subsurface for two reasons. First, orbiting sounders have the potential to provide planet-wide information about gross crustal structure, lateral heterogeneity, and perhaps even the depth to liquid water. Since Mars has no rainfall (at least today), the top of the groundwater may approximate a planet-wide surface of constant geopotential [2]. However, this expected distribution may be complicated by local processes, such as low- and high-temperature hydrothermal convection, compaction and tectonic displacement. If zones of shallower water could be discovered, it would be of high value in targeting a drilling mission.

Second, landed geophysical investigations have the potential for assessing the distribution of subsurface volatiles directly. Present models of the subsurface distribution of water and ice on Mars are poorly constrained, and additional data are sorely needed. In addition, landed geophysics can also provide important information about the structure, lithology, and physical properties of the intervening crust. Such data can make a significant difference in the choice of penetration technique, cuttings removal procedures, casing techniques, and drilling strategies. Indeed, terrestrial experience has demonstrated that, without this kind of information, a drilling investigation's likelihood of success is greatly diminished. ESA's NetLanders (a local array of seismometers) may be expected to provide the first useful seismic data set.

We plan to begin planet-scale mapping of Mars with ESA's 2003 Mars Express mission which has an Italian-US ground-penetrating radar experiment. We should, however, be cautious in expecting that Mars will cooperate and that these soundings will penetrate sufficiently deeply and be reliably interpretable. A second-generation ground-penetrating radar system is already being developed in concept (one that utilizes dual-receviers and operates at greater power) that can be expected to identify an ice/brine boundary to depths of five kilometers or more [3]. A global data set from such an orbital mapping mission will provide the information needed to select a short list of optimal sites for a drilling experiment intended to reach the top of the putative hydrosphere.

Drilling: The needed drilling technology for direct subsurface exploration is clearly not available within NASA or its aerospace contractors and is, in fact, significantly different from the technology in daily use within the petroleum and gas industries. Work has been underway for the last several years to develop the necessary competency with the help of other government laboratories, industry and academia [4].

Several types of drilling approaches have been proposed. Key differences include the depth of access, the mechanics of the bit and the means of clearing the hole, and casing strategies. Some of these designs can be supported by downhole data collection, others cannot.

We expect that ongoing systems studies will lead in the next year or so to the identification of the two or three most promising lightweight, autonomous drilling systems for martian application. Such systems will have to be capable of operating initially on solar powered spacecraft and will create what would be termed micro-boreholes on Earth -- holes 2 or 3 cm in diameter from which pristine cores a cm in diameter can be extracted. Before application on Mars these systems will have to prove themselves in various Mars-analog environments on Earth, most likely including Arctic and Antarctic sites. Given the poorly explored nature of the subterranean biosphere we may expect these terrestrial demonstrations to yield significant science results.

Post- or Syn-drilling data acquisition: There are two basic strategies for interpreting the subsurface lithology. First, an appropriate set of downhole measurements, which can be collected either during or after drilling, can provide powerful information. Such downhole data collection is possible with certain drilling designs, and not possible with others. Second, samples can be returned to the martian surface, either for analysis there, or for sample return and analysis at Earth. The astrobiology-related subsurface objectives require detailed sample analysis, rather than down-hole logging.

Water production: One of the goals of subsurface exploration is to deliver liquid water to the martian surface. If a deep (2-5 km) drill hole intersects the martian water table, it may be a formidable challenge to lift water from there to the surface. In addition, it is expected that there will be significant issues regarding wellbore stability and casing perforation.

An alternative strategy is to target water in the form of ground ice (which can be melted), which may exist in the form of massive lenses or simply within the pores of volcanic and sedimentary rock. The benefit of this approach is that such targets are likely to be present at much shallower depths. The chief disadvantages are that ground ice may yield more limited quantities of water, since it won't flow towards the wellbore unless melted (an operation that requires a significant amount of energy and whose maximum volumetric influence is limited by conduction). Finally, a third way to deliver water to the surface is to produce water vapor from the unsaturated zone that may lie between the base of the cryosphere and the water table at many locations. This has the dual advantage of requiring a

The Athena Pancam and Color Microscopic Imager (CMI). J.F. Bell III[1] , K.E. Herkenhoff[2], M. Schwochert[3], R.V. Morris[4], R. Sullivan[1], and the Athena Science Team. [1]Cornell University, Department of Astronomy, Ithaca NY 14853-6801, [2]USGS, Branch of Astrogeology, Flagstaff, [3]JPL/Caltech, [4]NASA/JSC.

Introduction: The Athena Mars rover payload includes two primary science-grade imagers: Pancam, a multispectral, stereo, panoramic camera system, and the Color Microscopic Imager (CMI), a multispectral and variable depth-of-field microscope. Both of these instruments will help to achieve the primary Athena science goals by providing information on the geology, mineralogy, and climate history of the landing site. In addition, Pancam provides important support for rover navigation and target selection for Athena *in situ* investigations. Here we describe the science goals, instrument designs, and instrument performance of the Pancam and CMI investigations.

Table 1. Pancam Science/Operations Goals

- Obtain color panoramic images of the entire landing site, to assess the local geology, determine its regional context, and guide the selection of the most interesting *in situ* sampling targets.
- Obtain high spatial resolution images (mm-scale) of small-scale morphologic features and *in situ* sampling targets.
- Resolve objects to distances of 100 m or more and provide stereo coverage adequate for the generation of digital terrain models of the landing site and for guiding rover traverse decisions.
- Obtain 12-color visible to short-wave near-IR images of selected regions to determine surface color and mineralogic properties and to guide selection of *in situ* sampling targets.
- Obtain images of the Martian sky, including direct images of the sun to determine dust opacity.

Pancam: The scientific and operational goals of the Pancam investigation are summarized in Table 1. Multiple functions are provided in a single instrument package: Full 360° azimuth and ±90° elevation imaging for morphologic, atmospheric, and geologic process studies; stereo imaging for 3-D site characterization and rover trafficability issues; and multispectral imaging for rapid constraints on the mineralogy and color properties of the scene.

Pancam utilizes two 1024×1024 Loral CCD detector arrays (12 μm pixels) that are identical to the arrays used in the Cassini imaging system. Each array is masked down to a 1024×512 active area and used in frame transfer mode. Each camera is combined with optics and a small filter wheel to become one "eye" of a multispectral, stereoscopic imaging system. The optics for both cameras consist of identical 4-element symmetrical lenses with an effective focal length of 38 mm and a focal ratio of f/18, yielding an IFOV of 0.31 mrad/pixel, or a rectangular FOV of 18.2°×9.1° (azimuth × elevation) per eye. The two eyes are separated by 28 cm horizontally and have a 1° toe-in to provide adequate parallax for stereo imaging. The optical design allows Pancam to maintain optimal focus from infinity to within a few meters of the rover, and to allow only a few pixels of defocus at closer ranges. Each eye also contains a small 8-position filter wheel (Table 2) to allow surface mineralogic studies and multispectral sky imaging in the 400-1100 nm wavelength region. Signal to noise ratio (SNR) for both clear and color imaging will exceed 200 for nominal martian observing conditions.

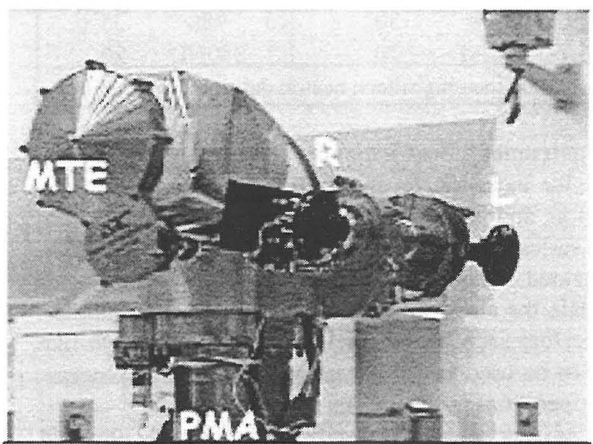


Figure 1: The left (L) and right (R) flight Pancam cameras atop the flight PMA. The mini-TES elevation mirror (MTE) is above and behind the cameras.

Pancam's flight software provides the capability to perform simple onboard image processing, high- and low-level commanding, and optimized wavelet-based compression based on the JPL ICER routine.

The two Pancam cameras are mounted on the Pancam Mast Assembly (PMA; Figure 1), which also includes several key components for the Athena Mini-TES instrument. The PMA is erected to the vertical position by a deployment actuator at its base, raising the cameras to a height of approximately 2 m above the surface. The cameras are oriented horizontally with a boresight 180° from the Mini-TES boresight; coalignment is through a shared Pancam/Mini-TES azimuth actuator and separate elevation actuators. Hard stops are provided for all actuation axes.

Pancam will be used with other Athena instruments to maximize the overall mission science return. Examples include providing context for Mini-TES spectral data and CMI images, providing high spatial resolution local documentation of sampling targets for *in situ* Mössbauer and APXS analyses, providing assessment of the degree of dust coatings on rocks, and monitoring of diurnal atmospheric dust opacity and daily surface dust deposition rates.

Table 2. Pancam Multispectral Filters

LEFT			RIGHT		
Name	Wvl (nm)	FWHM (nm)	Name	Wvl (nm)	FWHM (nm)
L0	650	150	R0	650	150
L1	750	20	R1	750	20
L2	670	20	R2	800	20
L3	600	20	R3	860	25
L4	530	20	R4	900	25
L5	480	25	R5	930	30
L6	430	30	R6	980	35
L7	440ND	20	R7	880ND	20

ND=Solar imaging filters; neutral density=5

Instrument Performance: Pancam was originally built for inclusion on the 2001 Mars Surveyor lander mission, and so the cameras have undergone an extensive series of component-level, standalone, and PMA-integrated calibration and test activities. These tests validate the electronic, optical, spectral, and radiometric performance of the cameras and provide flight-like data to be used in the development of image processing, operations, and analysis tools.

CMI: A wealth of information can be obtained through studying rocks and regolith with microscopes that have resolution sufficient to enable detailed characterization of individual mineral grains, clasts, or particles in rocks. Such characterization is particularly important for sedimentary rocks in past aqueous environments, as size, angularity, shape, and sorting of grains can reveal the conditions under which the material was transported and deposited. Microscopic imaging also provides useful information on volcanic rocks and impact breccias. Vesicularity gives an indication of volatile content. Grain size and texture provide information on crystallinity of the magma when emplaced and how quickly it cooled. The optical properties of mineral grains constrain their mineralogy and allow improved identification when coupled with Pancam, Mini-TES, APXS, and Mössbauer data.

CMI uses the same CCD array and filter wheel assembly as Pancam. CMI's optics yield a field of view (FOV) of 30×15 mm, with 30 μm/pixel resolution, similar to that of a field geologist's hand lens. Diffraction limits the focal ratio to < f/10, so that the depth of focus is < 3 mm. The topography of natural rock surfaces commonly exceeds this depth over the length scale of the instrument's FOV, so some form of focus control is necessary. The baseline CMI design achieves this by using some filter wheel slots for optical elements that adjust the focus position either in or out with respect to the nominal focus position. This allows for a simple arm design in which the CMI is driven against a contact sensor and then held there motionless while imaging takes place. Translation of the CMI FOV can also provide stereo micro-imaging.

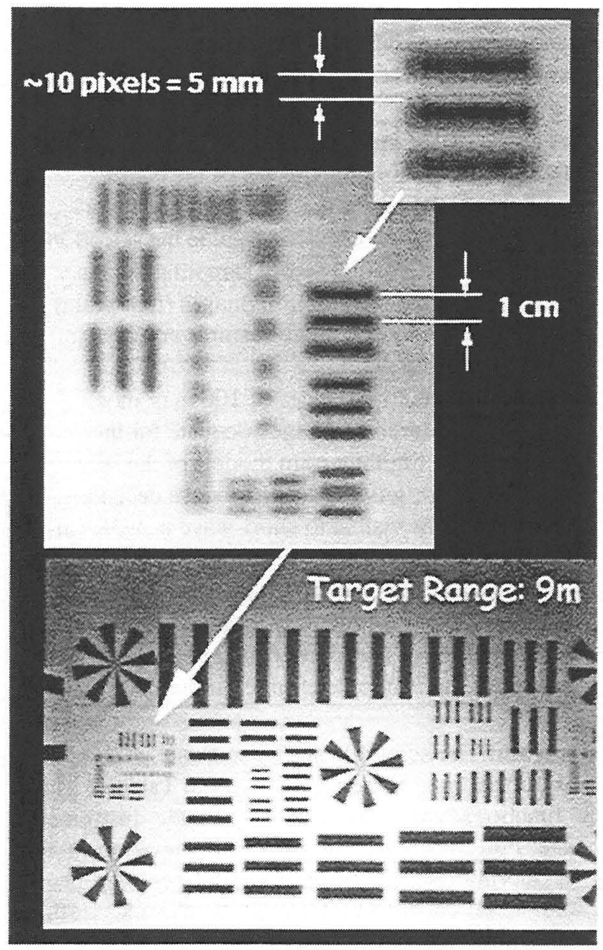


Figure 2: Example Pancam image of a geometric target at 9 meters range. Pancam's 0.31 mrad IFOV is clearly able to resolve features 5 mm and smaller at this range.

INVOLVEMENT OF AEROSPATIALE MATRA LANCEURS (AML) IN THE EXPLORATION OF MARS.
Ph. Berthe[1] and Francine Bonnefond[2], [1]Aerospatiale Matra Lanceurs, Saint-Médard-en-Jalles, [2]Aerospatiale Matra Lanceurs, Les Mureaux.

The goal of this paper is to present to the workshop participants the Aerospatiale Matra Lanceurs company and its activities in the field of Mars exploration. Aerospatiale Matra Lanceurs (AML) is a subsidiary of the EADS ("EADS in formation") group. This company has all the expertise required to develop strategic missiles, space launchers, orbital transfer vehicles, re-entry vehicles and equipment for space research and interplanetary exploration. Therefore it can provide useful information and answers to the "how" and "when" questions in this workshop: AML is the Industrial Architect for Ariane 4 and for all the different, present and future versions of Ariane 5. It has built the thermal protection system of the Huygens Titan Probe which is carried by Cassini. In addition to the thermal protection production, Aerospatiale Matra Lanceurs has also performed all the studies linked to the entry and descent system, including the aerodynamic studies, trajectories, heat and radiation flux in an atmosphere, the one of Titan, different from ours.

AML has also been the prime contractor of the Atmospheric Reentry Demonstrator (ARD), launched by Ariane 5, which flew flawlessly in October 1998.

Due to its prominent role in Europe, Aerospatiale Matra Lanceurs is now playing an important part in the present and future French and European endeavors regarding the exploration of Mars. For some elements, such as Beagle-2, the involvement of Aerospatiale Matra Lanceurs has already been decided, for some others, this is still a competitive process.

Participation in Beagle-2 - The Beagle 2 project is the British led effort to land on Mars as part of the European Space Agency's Mars Express Mission to be launched in June 2003. The Beagle 2 probe comprises the lander and the Entry, Descent and Landing System (EDLS) with specialized mechanical and electrical interface units. The entry system comprises a front shield/aeroshell, a back cover/bioshield and release mechanisms. It protects the lander from contamination whilst on Earth, from the space environment during the six months to get to Mars and during entry into the Martian atmosphere. Aerospatiale Matra Lanceurs has been selected and will build the heat shield of Beagle-2 under the responsibility of Martin Baker Aircraft (UK), within an industrial team led by Astrium, another company of the EADS group.

Bid for the Netlanders – Aerospatiale Matra Lanceurs is a candidate for the Industrial Lead in the development of the Netlanders, a network of four small (66 kg – 145 lbs.) geophysical stations which could be launched to Mars as early as 2005. These Netlanders are the elements of a French program, with the participation of a few European partners. The initial plan was to launch them together with the Mars Sample Return Orbiter using an Ariane 5.

Bid for the Mars Sample Return aerocapture heat shield – In the previous Mars Sample Return Mission scheme, it was foreseen that France would provide, for the Mars 2005 mission, the Mars Sample Orbiter. In order to save propellant while reaching the orbit of Mars, it was foreseen that the French Orbiter would perform an aerocapture maneuver. Aerospatiale has made a proposal for the large (max. diameter = 3650 mm – 12 ft.) aerocapture heat shield. Such a maneuver would have been a world first.

In addition, Aerospatiale Matra Lanceurs has made a bid in association with Astrium for all the guidance studies during the aerocapture phase. AML has all the expertise necessary for such a maneuver: aerodynamics aspects, trajectories, navigation and guidance.

Even if the Mars Sample Return mission is postponed, the technology of aerocapture remains a very promising way to meet the Mars mission goals in terms of performance, and the knowledge and technologies acquired by Aerospatiale Matra Lanceurs will be used in the future.

Aerospatiale Matra Lanceurs can also bring its expertise in the field of launcher technology.

Ariane 5 – As already stated, Aerospatiale Matra Lanceurs is Industrial Architect of the Ariane 5 launcher. The upgraded versions of Ariane 5, with a cryogenic upper stage, called Ariane 5 ECA and ECB, will be particularly well suited to launch heavy payloads towards Mars. As an example of escape mission, Ariane 5 ECA is intended to launch payload towards Mars. Such mission requires a C_3 = 18 km²/s² and the corresponding performance is **5 200 kg** (11,500 lbs.) . Ariane 5 ECB is even more powerful.

Soyuz – Beagle-2 will be integrated onto the ESA Mars Express spacecraft. The launch window is early June 2003 and the mission will leave from Baikonour on a Soyuz/Fregat rocket supplied by Starsem. This launcher has been successfully flight tested twice in 2000. Aerospatiale Matra Lanceurs has been the instigator and is the main shareholder of Starsem, making the cost-effective Soyuz available for planetary missions such as Mars Express. Aerospatiale Matra Lanceurs ensures industrial coordination for the preparation of payloads at the Baikonour launch site.

Conclusion – This brief overview shows that whatever the scenario, Aerospatiale Matra Lanceurs will be present in future Mars Exploration, from the beginning of the mission with the launchers to the actual Mars surface operation and the return of payload. Our company is willing to be part of the new cooperative scheme that will be defined between France and the United States for the exploration of Mars and the return of Mars Samples.

TERMOPAC: a generic experiment for the long term monitoring of the Martian Thermosphere.

J.J. Berthelier (1), E. Chassefière (2), L. Duvet (1), F. Forget (2), P. Touboul (3), S. Bougher (4)

(1) *CETP/IPSL, 4 Avenue de Neptune, 94100 Saint-Maur, France*

(2) *LMD/IPSL, UPMC, 4 Place Jussieu, BP 99, 75252 Paris Cedex 05, France*

(3) *ONERA, 92 Chatillon, France*

(4) *Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ85721, USA*

1-Scientific Objectives.

Besides its variations related to solar cycle and seasonal effects, the Martian thermosphere also displays specific responses to propagating gravity waves, dust storm heating and interaction with the solar wind. All these effects, which strongly affect the density and temperature structure of the upper atmosphere as well as the wind pattern, are of significant importance for the understanding of the dynamics and of the short and long term evolution of the global planetary environment.

As a matter of fact, on going studies have shown that the lower and middle atmosphere are rather sensitive to conditions in the thermosphere; consequently, numerical simulations of the Martian meteorology through General Circulation Models require that the boundary conditions be known with a good accuracy at thermospheric altitudes as high as 150 km and even higher.

In this altitude range, the coupling with the solar wind and its consequences on energy input both depend upon and influence the large scale structure of the upper atmosphere. The long term evolution and erosion of the atmosphere by the solar wind definitely appear as a key question to be investigated by the future Martian program. A detailed and quantitative understanding of the various mechanisms which can presently play a role is needed to estimate their effectiveness back over the geological times and describe their possible effects on the climatic variations. This can only be achieved through a precise knowledge of the structure thermosphere and of its temporal variations.

Last but not least, insertion in Mars orbit of future scientific or telecommunication satellites will certainly rely on aerocapture and aerobraking which, compared to the classical chemical technique, allow for a very large mass saving. Reliable and safe orbit insertion and orbital operations require that accurate models of the structure of the atmosphere and its predicted variations be available.

The response of the Martian environment above ~100 km to the various processes mentioned above are at present very poorly constrained by available measurements. Upcoming missions to Mars such as Planet-B and Mars Express will not provide in situ measurements down to the lower thermosphere of Mars, in the altitude range between 100 and 150 km where considerable variability has been observed recently by the Mars Global Surveyor (MGS) Accelerometer during aerobraking campaigns [1]. The Mars Thermospheric General Circulation Model (MTGCM) is a 3-D modeling tool that is presently being used to simulate the Mars upper atmosphere structure and dynamics in the altitude range from ~ 70 to 300 km [2]. The simulation runs for various solar fluxes, seasons, and dust heating conditions were only crudely constrained by Mariner, Viking, Pathfinder, and MGS observations since the available in-situ data span only a fraction of the solar cycle and Mars seasons. A long-term program to monitor the structure of the Martian thermosphere from ~100 km up to ~ 250 km is thus proposed which can take benefit of multiple opportunities to provide the necessary coverage of the various conditions which affect the global environment of Mars. The ultimate goal is to build a data base for the climatology of the lower thermosphere of Mars which can be used to constrain the models.

2-Instrumentation.

The proposed package consists of a three-axis accelerometer coupled with two density gauges. Such a package, which is already part of the proposed Dynamo payload [3] could be flown on board future orbiters of the Mars program. It is devoted to the measurement of densities, temperatures and winds in the 100-250 km altitude range, that is inside and up to • 80 km above the aerobraking altitude range (100-170 km)

2.1-Accelerometer

The accelerometer operates in the aerobraking range (100-170 km). Whereas measurements of cross-track and radial components are expected to give access to the horizontal wind, mainly zonal in near-polar orbits, and possible transient vertical winds due to propagating waves, as shown by previous satellite investigations of Earth's thermosphere [4] combined measurements of both on-track acceleration and atmospheric density by pressure gauges (see below) will be used to discriminate between density and wind effects along on-track direction i.e. mainly from meridional winds. The sensitivity of the accelerometer would be larger than on MGS by at least one order of magnitude. The three axis acceleration measurement system directly derives from existing instruments already studied and built for several ESA (CHAMP) or NASA (GRACE) missions. The foreseen total range of measurement is 0.3 mg, with an anticipated noise of 50 ng at frequencies larger than 10^{-2}-10^{-3} Hz. The spatial resolution along the satellite trajectory is better than • 10 km and the cross-track and radial winds could be measured with an accuracy of • 40 m/s.

2.2 - Density gauges

The density measurement system operates in the full 100-250 km range and makes use of two subsystems each consisting of two closed pressure gauges following an idea initially proposed in [5] to determine spacecraft attitude. The principle is to perform pressure measurements along 4 directions at ~ 45° from the spacecraft orbital velocity and by differential measurements determine the true ram velocity direction. Provided that the spacecraft velocity is much larger than the atmospheric gas bulk velocity, which is the case on Mars, these 4 measurements allow to deduce the density. Rotating one group of pressure gauges so that one of the gauges is looking perpendicular to the spacecraft orbital velocity allows to retrieve the Mach number and then deduce the temperature. The operation of such a system was simulated numerically and results were used to obtain preliminary values of the accuracy of such measurements. If the gauges are carefully positioned in order that no particle scattered from the spacecraft or its appendages can enter the accommodation chamber, the accuracy of the parameters derived from differential measurements (direction of the true ram velocity and Mach number) are pretty good, on the order of ~ 0.25° and typically ~ 1% respectively. Absolute measurements of density and temperature can be obtained with errors of ~ ± 5% and 10% respectively; a more precise measurement of the temperature can be achieved through the determination of the scale height. The relative accuracy on these parameters, thus the accuracy of measured small scale variations, is much better and should reach a few percent. The temporal resolution could be on the order of a few tenths of a second for the ram velocity direction and density, and 1 to 2 seconds for the Mach number and temperature. The estimated weight of the complete pressure gauge system including electronics is 1.1 kg. Accelerometer and density gauge measurements are complementary and their partial redundancy in the aerobraking range (100-170 km) will be of a great interest for comparison and cross-calibration purposes.

3-References.

[1] Keating,G.M., et al., The structure of the Upper Atmosphere of Mars: in-situ accelerometer measurements from Mars Global Surveyor, *Science*, 279, 1672-1676, 1998.

[2] Bougher, S.W. et al., The Mars Thermosphere, 2. General circulation with coupled dynamics and composition, *J. Geophys. Res.*, 95, 14811-14827, 1990.

[3] Chassefière et al., this conference.

[4] Hanson, W.B., et al., a satellite anemometer, *J. Astron. Sci.,* 40, 3, 429-438, 1992.

[5] Marcos, F.A., and Forbes, Thermospheric winds from satellite electrostatic triaxial accelerometer system, *J. Geophys. Res.,* 90, 6543-6552, 1985

ARES, an electric field experiment for NETLANDER

J.J. Berthelier[(1)], R. Grard[(2)], H. Laakso[(3)] and M. Parrot[(4)]

(1) *CETP, 4 Avenue de Neptune, 94100, Saint-Maur, France,*
(2) *(2) ESA/SSD, ESTEC, 2200 AG Noordwick, THE NETHERLANDS,*
(3) *(3) FMI, PO Box 503, 00101, Helsinki, FINLAND,*
(4) *(4) LPCE, 3A Avenue de la Recherche Scientifique, 45071 Orléans Cedex 02, France.*

1-Scientific Objectives.

The conditions which prevail in the atmospheres of most planets in the Solar System, in particular the telluric ones, are likely to give rise to their electrification. The resulting processes, which are of major importance for meteorology and climatology on Earth, may also be significant for atmospheric and surface processes on the other planets and specifically on Mars.

With an average pressure between 5 and 10 mb, the atmosphere near the surface of Mars is comparable to the Earth's stratosphere at an altitude of 35 to 40 kilometers. The main difference lies in the composition, since the major constituent on Mars is the carbon dioxide CO_2. Ionization is mainly due to cosmic rays and during daytime, photo-ionization by solar EUV and soft X-rays. In absence of actual data, most authors have assumed that the electric conductivity of the atmosphere at ground level is ~ 10^{-11} S/m, comparable to the values measured in the terrestrial stratosphere at an equivalent pressure, increasing with altitude at a rate defined by the atmospheric scale-height.

Owing to its large conductivity, the lower ionosphere of Mars can be considered equipotential. On the surface of the planet the situation is different from the case of the Earth: due to the lack of liquid water, at least down to a depth possibly larger than ~1 km, the ground electric conductivity is certainly rather small, with values in the range 10^{-10} to 10^{-12} S/m quoted by most authors. If the free electron density varies, as indicated by models from less than 1 electron/cm^3 at night to 10^2 electrons/cm^3 during daytime, the situation may be complex depending on the ground conductivity with the Martian soil appearing with respect to the atmosphere as a conductor during night and as an insulator during daytime.

Various physical mechanisms can generate electrical charges in the lower atmosphere of Mars. The emission of photo-electrons by solar UV leaves the surface charged, dust particles also get charged due to solar UV radiation and to collection of photo-electrons. The efficiency of triboelectricity or contact electrification near the surface of Mars certainly makes it a process of major importance in the presence of large wind velocities. Observations from the earlier Mars missions [1], [2], have consistently shown that the Martian surface and atmosphere are filled with a highly mobile dust population. Dust particles can be transported by ordinary "fair weather" winds but extreme conditions are encountered during dust storms when particles are blown and raised from the ground with velocities from several tens to ~ 200 meters per second. Under such circumstances, the mechanisms for dust charging are similar to those encountered on Earth during desert sand storms when large electrical charge densities can develop, varying from ~ 10^{-9} C/cm^3 up to 10^{-6} C/m^3 in the case of terrestrial dust devils, and give rise to locally enhanced electric fields. The specific conditions of the Martian atmosphere, namely a CO_2 dominated composition and a low pressure, may even enhance the contact electrification of dust particles but the breakdown threshold, estimated to be on the order of 20 kV/m, is lower than on Earth and limits the charge densities to lower values.

The consequences of the development of a large-scale electric field on Mars, together with very intense local field enhancements, are important in several domains. The first one is the transport of the dust particles themselves since, for micron size particles, electrical forces may become comparable to the drag forces. Another domain where the atmospheric electric fields may play a role is the surface material chemistry, as suggested by [3]. In addition, we may mention a more speculative domain of interest, life on Mars since it is well known that in planetary atmospheres, lightning and electrical discharges may have an influence on the production of chemical compounds and ultimately on biology.

As pointed above, a likely consequence of the atmospheric electrification is the occurrence of electrical discharges which, according to [4] can take two different forms: filamentary or glow discharges generating electromagnetic emissions with a widespread frequency spectrum. As on Earth, Schumann resonances can be excited in the lowest part of the ELF spectrum [5].

2-Instrumentation.

The very tight constraints imposed on the dimensions, mass and power of the NETLANDER instruments restrict the electric fields measurements to only one dimension, along the vertical direction. For obvious symmetry reasons, and as on Earth, the planetary large scale electric field of atmospheric origin must be essentially vertical and this component is therefore of primary interest. We use the simple so called "double probe" technique to measure this vertical component, based on the measurement of the potential difference between 2 identical electrodes and flown with success on numerous stratospheric balloon flights. The effect of dust impacts on the electrodes have been estimated by [6] not to be of major concern for the planned measurements.

The sensors are simple cylindrical electrodes with an area of ~100 cm^2, large enough to provide a coupling resistance with the surrounding medium much smaller than the input impedance of the preamplifier. One of the electrodes will be positioned approximately 1 m above the main body of the lander and as far as possible from other grounded or polarized surfaces.

The atmospheric electric conductivity is measured by measuring the time constant for the electrodes to recover their equilibrium potential after having been short-circuited to ground.

The electronics consists of high impedance preamplifiers followed by conventional DC and AC amplifiers to measure the electric fields in various ranges of frequency. For AC electric fields measurements, data will be transmitted either through 3 filters, with frequency bandwiths typically 10-40 Hz, 40-160 Hz, and 160-1000 Hz, or through a waveform channel, depending on the mode of operation and telemetry capability. The *digital unit* consists mainly in an FPGA, a 16 bit ADC converter and a ram memory with a capacity of ~ 8 kbytes to store data during time intervals of ~ 1 second and transmit them to the CDMS.

References.

[1] Greeley, R., N. Lancaster, S. Lee and P. Thomas, Martian aeolian processes, sediments and features, in *Mars* edited. by H.H. Kieffer et al., p 730-766, Univ. of Arizona Press, Tucson, 1992

[2] Chassefière, E., J.E. Blamont, V.A. Krasnopolsky, O.I. Korablev, S.K. Atreya and R.A. West, Vertical structure and size distributions of Martian aerosols from solar occultation measurements, *Icarus,* **97**, 46-69, 1992

[3] Grard, R., Solar photon interaction with the Martian surface and related electrical and chemical phenomena, *Icarus,* **114**, 130-138, 1995

[4] Farrell, W.M., M.L. Kaiser, M.D. Desch, J.G. Houser, S.A. Cummer, D.M. Wilt and G.A Landis, Detecting electrical activity from Martian dust storms, *J. Geophys. Res.*, 104, 2, 3795-3801, 1999.

[5] Sukhorukov, A.I., On the Schumann resonances on Mars, *Planet. Space Sci.*, **39**, 12, 1673-1676, 1991.

[6] Berthelier, J.J., R. Grard, H. Laakso, M. Parrot, ARES, Atmospheric relaxation and Electric field Sensor, the Electric Field Experiment on NETLANDER, *Planet. Space Sci.,* to be published, 2000.

European Tracked Micro-Rovers for Planetary Surface Exploration. R. Bertrand[1], G. Klingelhöfer[2], R. Rieder[3], M. van Winnendael[4], M. Zelikman[5], [1]von Hoerner & Sulger GmbH, Schwetzingen, Germany, bertrand@vh-s.de; [2]Univ. of Mainz, Germany, klingel@mail.uni-mainz.de; [3]Max-Planck-Institute for Chemistry, Mainz, Germany, rieder@mpch-mainz.mpg.de; [4]ESA-ESTEC, pputz@estec.esa.nl; [5]Space Systems Finland, Helsinki, Finland, mika.zelikman@ssf.fi.

Introduction: During the Mars Pathfinder mission, the 10-kg-rover Sojourner proved to be the enabling technology for efficient exploration of the landing site. At the same time as larger rovers are planned, certain missions also call for low-mass-rovers. They are needed not only to collect samples for return to Earth, but to deploy scientific instruments at relevant samples for in-situ measurements. For both mission types, the rover system must be as small and light as possible, accommodating a maximum of payloads or samples at the same time.

In Europe, nano-rover technology has been developed for many years. One of the most advanced concepts is the tracked microrover Nanokhod, developed most recently in the frame of ESA's Technology Research Programme. With a total rover mass of 2.55 kg it can accommodate four miniaturized scientific instruments with a mass of 1.1 kg in order to deploy and operate the instruments in the vicinity of a stationary lander. An upscaled version of the same rover concept can be used for deep drilling and sampling, as it is needed for example in future exobiology missions.

This paper gives an overview of the Nanokhod rover concepts and summarizes the development status as well as current and prospected activities.

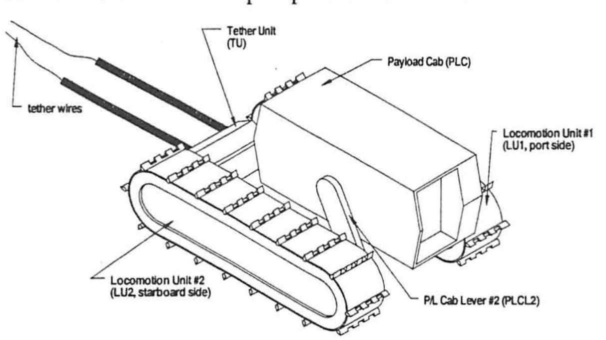


Fig. 1: Nanokhod Isometric View

Nanokhod Micro-Rover for In-Situ Measurements: The design of the Nanokhod, reaching back to early conceptual ideas at the Max-Planck-Institute for Chemistry in Mainz, Germany, is driven by scientific user needs with special emphasis on payload, and rather moderate locomotion requirements (operating distance from the lander: <50 m, total travel distance: < 100 m) [1]. Four payloads (APX spectrometer, Moessbauer spectrometer, microscopic camera, blower/grinder assembly) are integrated in a central payload cab, which is suspended between two tracked locomotion units by levers (Fig. 1). By this it is possible to orient all payloads very accurately to the same sample by simply rotating the payload cab and without the need to move the tracks (Fig. 2). Although the rover dimensions are only 220 x 160 x 65 mm, the vehicle can overcome obstacles as high as 10 cm. This is possible by using the payload cab as a climbing aid.

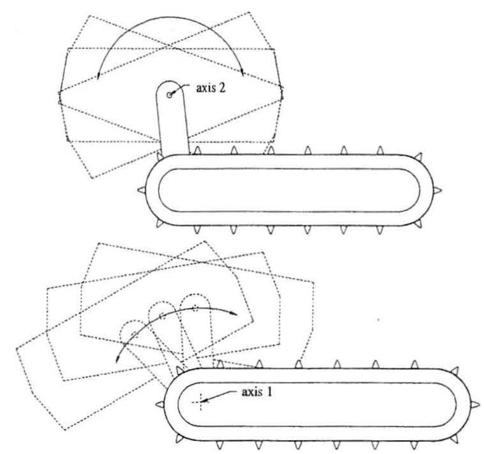


Fig. 2: Nanokhod Payload Cab Mobility

Power provision and telecommunication Nanokhod relies on the lander, to which the rover is linked via a thin tether cable. It is unrolled as the rover moves forward. The cable reservoir on the rover allows for the total travel distance of 100 m. In order to minimize power losses on the cable, power is transmitted at a voltage of about 100 V. In total, the rover system including payloads draws not more than 2 W and 3 W peak. All subsystems on the rover side are accommodated inside the track bodies. They are designed to operate with a purely passive thermal control system. For a Mars mission, operations would be possible at ambient temperatures between –80°C and +50°C. Below this range of temperatures, the rover would go in hibernation.

In order to control the rover on a unknown planetary surface, it is assumed that a stereo camera mounted on the lander can be used to acquire a panoramic image of the surrounding area. Based on the images, science and rover path planning will be performed by human operators on ground. The resulting sequence of waypoints as well as science instrument operations planning will be uploaded to the rover, which will be guided to the next waypoint autonomously, using again the lander camera or a laser pointer system. In addition to the lander based camera, the on-rover microscopic imager can be used for fine navigation at the scientific target sites.

EUROPEAN TRACKED MICRO-ROVER FOR PLANETARY SURFACE EXPLORATION:

R. Bertrand, G. Klingelhöfer, R. Rieder, M. van Winnendael, M. Zelikman

Within an ESA-funded research and technology development activity "Micro-Robots for Scientific Applications" (Micro-RoSA), a conceptual design baseline was developed covering all subsystems of the Nanokhod rover. Furthermore, an advanced laboratory model was designed and built, allowing for tests on locomotion capabilities and payload accommodation (Fig. 3). Further tests addressed aspects of critical technologies, such as the tether, deep temperature and vacuum resistance of single components (motors and sealings).

Fig. 3: Nanokhod Laboratory Model climbing a Slope on Mars Soil Simulant

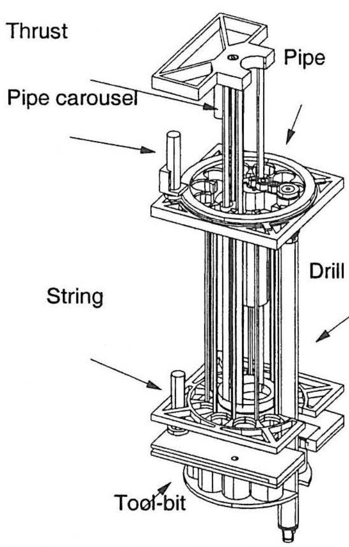


Fig. 4: Drilling and Sampling Subsystem for Accommodation in the Nanokhod Payload Cab

Nanokhod for Sub-Surface Sampling: Another ESA technology development activity called Micro-RoSA 2 currently underway focuses on drilling and sampling using an upscaled Nanokhod-type rover [2]. The requirements call for the capability to drill up to 2 meters into regolith and up to several centimeters into rocks or stones. Samples are to be taken at a given depth allowing to investigate soil layering and preserving the morphology of the sample. Fig. 4 shows the Drilling and Sampling Subsystem (DSS). Within a volume of 110 x 110 x 350 mm and a mass envelope of 5 kg, it contains up to 9 separate drill pipes and drill bits in two carousels. Besides the rotative/pushing mechanics, drilling can be supported by percussion using an ultrasonic transducer which is integrated in the bottom pipe. The DSS is designed to be mounted in a bridge structure in place of the instrument payload cab (Fig. 5). The rover carrying this payload would be of course larger with a total mass of about 12 kg.

The Micro-RoSA2 activity will produce laboratory prototypes of the DSS to be mounted on a rover mock-up, as well as a docking and sample delivery port, which would receive the samples collected by the rover on a stationary lander.

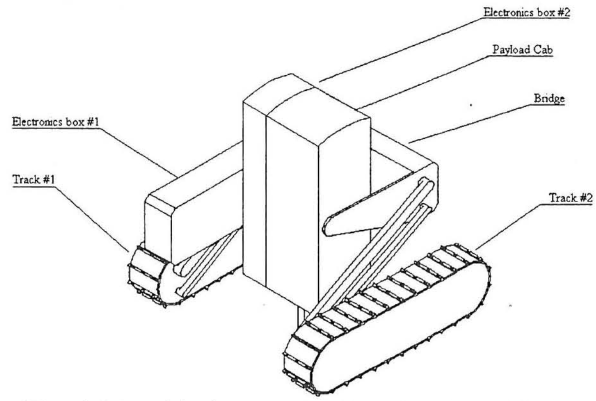


Fig. 5: Nanokhod Rover Mockup for Deep Drilling

Conclusions and Outlook: Design and development work in Europe on the Nanokhod micro-rover for scientific surface exploration has progressed to a state, where the technical feasibility has been or is currently demonstrated by advanced laboratory models. Besides a small Nanokhod rover for in-situ measurements, these activities also include deep drilling and sampling on a larger version of this rover (Micro-RoSA2). Another complementary activity called "Payload Support for Planetary Exploration" focuses on a complete end-to-end control system for a Nanokhod-type rover, leading to a demonstrator for system testing. Finally, a continuation of the Micro-RoSA has been initiated in order to address in detail all issues of environmental compatibility of a Nanokhod rover, including a complete system environmental test. This all together will lead to a sound basis, where a Nanokhod flight model can be finalized with low risk and within 2 to 3 years.

References: [1] Bertrand, R. et al: Nanokhod Microrover for Scientific Missions to Mars; IAF-99-Q.3.07; [2] M. van Winnendael et al.: Nanokhod Microrover heading towards Mars. I-Sairas'99, ESA-SP-440, 1999.

MARS MINERALOGY. R.Bianchi, Consiglio Nazionale delle Ricerche – Istituto di Astrofisica Spaziale – Via del Fosso del Cavaliere 100 – 00133 Roma – Italy (rbianchi@ias.rm.cnr.it).

The study of surface and subsurface mineralogy of martian soil and rocks is the key for understanding the chemico-physical processes that lead formation and evolution of the red planet. The water and other volatiles history, as well as weathering processes are the signatures of present and past environmental conditions, associated to the possibility for life.

Besides the detection of the major chemical elements (Na, Mg, Al, Si, S, K, Ca, Ti, Fe) to characterize the Martian sample petrography, the possibility to retrieve information on chemical trace elements (K, Rb, Cs, Ba, Sr, Ti, Zr, Rare Earths, U, Th) allows the identification of the differentiation processes during the planet accretion as well as the geodynamical evolution of planetary layers and surface material alteration.

Trace elements distribution in Martian superficial materials depends on their geochemical behavior:

- during magmatic differentiation processes; partial or complete melting of silicates during the primordial planetary differentiation and successive volcanism;
- during secondary processes; metamorphism, chemical and physical alteration and erosion.

For example: Sr^{2+} due to its ionic radius (1.12 Å) can substitute either Ca^{2+} or K^+ in crystalline structures and Sr/Ca Sr/K ratios are indicators on fractional crystallization level and, in conjunction with other trace elements detection, on the nature of the original magma.

Rocks with sedimentary origin presents high concentrations (of the order of 10^2 ppm) of Zr, as well as low contents in Cs.

High concentrations of Zn, Hf, Nb, Ta, and Rare Earths (REE) are related to high contents of volatile elements.

Rare Earths are particularly adequate for magmatic processes characterization because of regular decreasing of their incompatibility degree from La up to Lu and because of the sensitivity of Eu and Ce to oxidizing-reductive conditions. Thus Rare Earth can be used to characterize the Martian oxide-reduction state during primordial differentiation, as well as to determine the nature of rocks (basalt-granite-metamorphic-sedimentary).

IR spectroscopy and Alpha-Proton-X ray spectroscopy (APXS) are proven technologies. They furnish basic information concerning the mineralogy and the abundance of the major chemical elements. Two experiments and relative instrumentation deticated to Mars mineralogy characterization have been already proposed to and accepted from the Italian Space Agency (ASI) as part of the *in-situ* analysis laboratory known as IPSE (Italian Package for Scientific Exploration) to be landed on the martian surface in the framework of the NASA Mars Global Surveyor Program.

Within IPSE measurements of major chemical elements and characterization of the mineralogy and microphysical structure is performed by means of MARS-IRMA (InfraRed Microscope Analysis) instrument, while measurements of the chemical trace elements by means of Ma_FluX (Mars Fluorescence X), a French-Italian instrument.

IRMA is an infrared microscope with imaging capabilities which provide detailed information on:

- texture, habit and microphysical properties (such as porosity) of the grains and particulates of the Martian soil as well as the petrography of martian rocks, with a spatial resolution of the order of the tens of micron;
- mineralogical composition and relative abundances of the rocks and soils, with a relative accuracy of the order of 1%.

Ma_FluX implements a new approach based on a new generation of hard X-ray detectors (Cadmium Telluride - CdTe) to measure the fluorescence lines. The CdTe sensors will improve noticeably the performance of the XRF especially for the detection of heavier elements at hard X-ray energies (from Fe up to U). This implementation allows to investigate the interior of the samples with a depth of analysis that ranges between one millimeter to one centimeter. In comparison, APXS investigates the surface of the samples with a typical depth which ranges only from a few tenths to some tens of micrometers. Furthermore, the instrumentation defines precisely the X ray absorption capacity of samples and it allows to estimate the abundance of elements heavier than iron.

The Mars Exploration program has been thought to bring back to Earth a limited amount of samples. However the *in situ* sample analysis is crucial to address in advance the geological environmental characterization associated to the sampling variety: materials from the old continental crust, volcanic products, sediments. *In situ* sample analysis is also crucial for any sample return selection and as backup for sample return failures.

Global and High Resolution Surface Mineralogical Mapping: OMEGA/MarsExpress, J-P. Bibring, IAS, Bat 121, 91405 Orsay campus, France, bibring@ias.fr.

Introduction: Our understanding of the Mars evolution is strongly limited by the scarcity of information concerning its surface mineralogical composition. Up to very recently, most of our global knowledge of the Mars history was derived from optical images, with the addition of the Viking Lander - followed and confirmed by the Pathfinder- soil analyses, and, to some extent, by the laboratory measurements performed on the presumed martian meteorites. The only assessments of the composition of geological units have been produced by the pioneering ISM/Phobos spectral images, followed recently by the TES/MGS ones. In spite of their limited spatial resolution, a few kilometers at best, they clearly demonstrate that the surface is not uniformly covered by the bright soil: darker uncovered areas are present over the entire Mars Surface, exhibiting distinct variations in composition, with a variety of silicates dominating the spectra. However, most key minerals have not been identified yet, as for potential carbonates for example, most likely because of a too large spatial sampling. The purpose of the OMEGA investigation, on board the Mars Express ESA mission, is to provide a global mineralogical mapping at a kilometer scale, with the capability of observing selected areas at a sub-kilometer (down to 300 m) resolution, in any targeted area over the entire martian surface.

Key science objectives: The prime goal is to determine the composition of the major surface materials (rocks, soils, ices and frost) and the atmospheric components, both gaseous (CO_2, CO and H_2O) and solids (aerosols), and to monitor their space and time variations. Spatial sampling as high as a few hundred meters (lateral, and vertical) should be achieved, with a SNR high enough to identify major and minor components down to a few percents in abundance. OMEGA should thus give access to the entire martian history, from geological time scales to seasonal variations, with a special emphasis to the large tectonic and metamorphic events, the volcanic history, and the cycle of volatile species, H_2O and CO_2 in particular.

The OMEGA Instrument: OMEGA is a visible - near IR imaging spectrometer, analyzing the diffused solar light. Its IFOV is 1.2 mrad, leading to a spatial sampling of some 300 m from an altitude of 250 km (close to periapsis), and 5 km from 4000 km. On each resolved pixel, OMEGA provides the spectrum onto 352 contiguous spectral elements ("spectels") a few nm large, from 0.5 to 5.2 μm. This spectral domains has been chosen because it contains the signatures of most potential constitutive surface and atmospheric materials, and in particular: most silicates, oxydes, hydrated minerals, ices and organic frosts. The visible part of the spectrum is analyzed on a bi-dimensional CCD detector (pushbroom mode); the IR spectrum is acquired onto two linear InSb arrays (whiskbroom mode), each cooled down 60K by a dedicated cryo-cooler; the spectrometer is passively cooled down 190K by a radiator. Data are compressed on board by a 21020 based microprocessor, using wavelet algorithm. OMEGA is developed under IAS responsibility (PI and PM), in cooperation with DESPA (Meudon, France), IFSI (Frascati, Italy) and IKI (Moscow, Russia).

The Mars Express Mission: First of the "F" (flexible) ESA mission, Mars Express will be launched in June 2003, to be Mars inserted late December 2003. Its nominal lifetime is one martian year, extendable to two. Its orbit has been chosen elliptic, to allow both high resolution observations close to periapsis, and global coverage from higher altitudes (up to several thousands). It will carry 7 orbital PI investigations, and deliver a Lander for exobiological studies. Most of the instruments, including OMEGA, are based on spare units of instruments developed for the Mars 96 russian mission, lost at launch.

Conclusion: OMEGA will provide the first kilometer and sub-kilometer surface and atmospheric spectral mapping of Mars. It should offer major contributions to a large variety of scientific fields, in comparative planetology (planetary evolution, tectonic activity), up to climatology and exobiology. It should in particular play an important role in identifying sites optimized to perform in situ measurements, and to collect samples for the MSR missions.

Let Mars Sample Return be launched in 2007 ! J-P. Bibring[1], J-L. Counil[2] and C. Sotin[3], [1]IAS, Bat. 121, 91405 Orsay Campus, France, bibring@ias.fr, [2]CNES, Toulouse, France, Jean-Louis.Counil@cnes.fr, [3]Nantes University, France, Christophe.Sotin@chimie.univ-nantes.fr

Science rationale: the laboratory investigations performed on extraterrestrial samples (lunar, meteorites, micrometeorites) over the past decades have demonstrated their unique capability of providing key data to understand the formation and early evolution of the Solar System. With Mars, we deal with a planet having gone through all steps of planetary activity, to a much higher level than underwent by the Moon and the small bodies, till its geological death, and without global resets: Mars has the potential to have recorded all major events over the entire and complex planetary evolution, including those linked to the organic evolution towards living organisms. Thus, the scientific outcomes of laboratory investigations on martian samples will serve a much wider community, including geophysics and geochemistry, planetology and climatology, atmospheric science and biology. Today's instrumental tools already give access to most properties at a grain size, a few micrometers in dimension. Within this decade, more sophisticated tools will still increase our capability of non destructive analyses (such as synchrotron X and IR coupled spectrometry), allowing the same samples, including individual grains, to be fully and sequentially analyzed for complete compositional determination: elemental, isotopic, molecular and mineralogical. For example, on the same grains, the mineralogical and organic content will be determined before the datation be performed. The studies of extraterrestrial samples have demonstrated that some key information are only observable at a microscopic scale. For Mars samples, it may well be that carbonates, for example, will not be present at macroscopic scales, but rather as tiny inclusions within breccias, and/or as individual grains in the soil. If organic activity is to be found in association with such material, only laboratory combined investigations will have the potential to decipher the clues of the past surface activity, when liquid water was stable (if ever).

The situation in France: driven by the MSR mission, the Mars exploration program includes several other important contributions, such as the participation to the Mars Express project, and the development of the Netlanders, focussed on the sounding of the martian interior; all these contributions are given dedicated presentations. It is fair to say, however, that the large involvement of France in this exploration depends on the contribution to the first sample return from Mars. This was the major objective, for a very broad scientific community, to obtain from our major institutions (led by our Ministry for Research and Education, CNES and CNRS) to initiate a Mars Exploration Program, at a scale never experienced before for any scientific space exploration program in France. The latest event within this program has been the issuing of an AO for contribution to this program at this preliminary phase, intended to participate to this end-to-end program, and get prepared to be selected whenever the international AO for Mars sample analyses will be issued. Despite the fact that this AO was only the first of a series, issued some 8 to 10 years before the foreseen dates for the samples to be available, more than 40 integrated proposals (including many consortium proposals) were received to be presently being reviewed, by an international board of experts. These proposals involve more than 300 scientists, within about 100 French institutes, in very broad fields. Only two proposals originate from the standard "space" institutes. It demonstrates how wide and enthusiastic the support of the MSR program is in France. In also indicates the basis on which both CNES and our government decide to support this program, to such an unprecedented level. The counterpart is the requirement that this program will happen within an horizon giving sense to the due effort. In that respect, a one window delay would be accepted if justified for increased robustness. However, the risk is huge for the support to be lost if the MSR program was shifted for drastic changes in scientific priorities.

PIGGYBACK MISSIONS TO MARS - POTENTIAL AND CONSTRAINTS B.Bischof[1] , H.Hoffmann[2], and M. Zier[3] ; [1,3]Astrium GmbH, Space Infrastructure, P.O. Box 28 61 56, D-28361 Bremen, Germany, bernd.bischof@astrium-space.com, manfred.zier@astrium-space.com, [2] Institut fuer Weltraumsensorik und Planetenerkundung, Rutherfordstrasse 2, D-12489 Berlin, Germany, harald.hoffmann@dlr.de

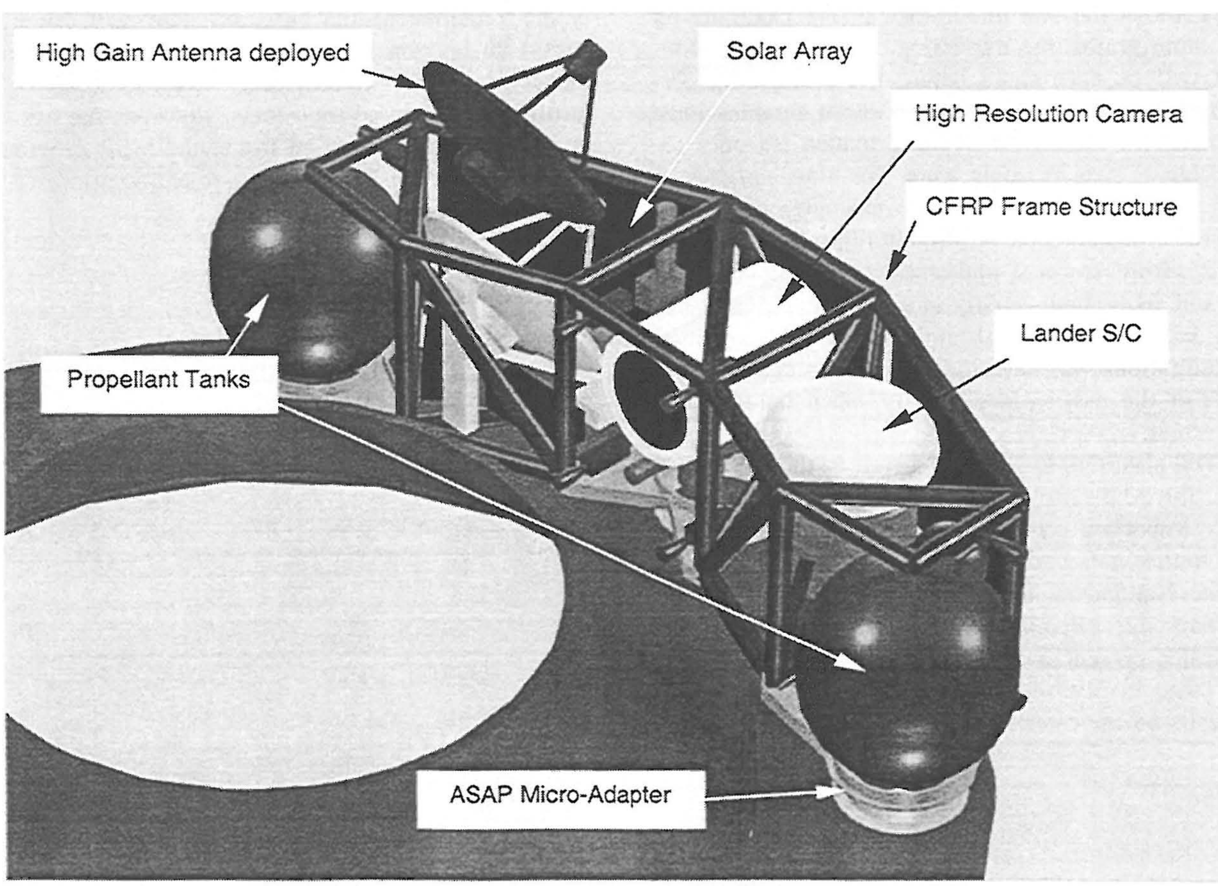
Introduction: For the near and medium future, any Mars exploration program will remain publicly funded. Therefore, the efficient use of taxpayer's money drives the overall long-term budget available for such a program as well as the cost envelope for each individual mission. Launches of commercial payloads to GTO offer launch opportunities at moderate costs for small piggyback payloads. Based on the corresponding capabilities of the ARIANE 5 launcher, a typical mission will be detailed, the general potential and constraints of such small missions to Mars will be described, and, finally, further applications will be indicated.

ARIANE 5 Piggyback: ARIANE 5 provides an adapter, ASAP, for additionally carrying small payloads to GTO. Dependent on the number of adapter mounting points to be used the allowable total mass of the piggyback payload starts at 120 kg for one point and reaches 360 kg for three neighbouring points. The launch service ends with the release of the small payload.

Mars-Orbiter Micro-Mission: As a typical small mission to Mars, presently a 360 kg piggyback payload is studied. The payload consists of a spacecraft to reach Mars orbit and to release a small lander, that utilizes an innovative technology for placing special experiment units on the Martian surface. The mission requirements and the conceptual design data will be presented as well as the envisaged research objectives. Finally figures for overall mission costs will be given.

A sketch of the overall accommodation of the ARIANE 5 piggyback payload is given below.

Potential and Constraints: Derived from this exemplaric mission, the potential and constraints of such missions will be briefly outlined. Examples will be indicated for further Martian research topics, that may be served via such missions, e.g., Mars plane for detailed observations of surface areas, tests of technologies for in situ production of ressources required for later manned missions



MINERAL IDENTIFICATION AS AN INDICATOR OF WATER AND GEOCHEMICAL HISTORY ON MARS.
Janice L. Bishop, SETI Institute, (jbishop@mail.arc.nasa.gov)
NASA-Ames Research Center, MS-239-4, Moffett field, CA 94035.

Introduction: Mineral identification on Mars is an essential aspect of basic geological science that will provide information about the climate and geochemical history of the planet and provide clues about the existence and extent of past water bodies or systems on Mars. Remote spectral data from orbiters, landers and rovers are the primary source of information about the surface mineralogy on Mars. Chemical and magnetic data also constrain the types or abundance of minerals present. The most successful mineral identification procedures will include data from a combination of spectral regions, as well as chemical and magnetic data. Other techniques, such as Mössbauer spectroscopy and thermal analysis (DTA, DSC, TGA), have been suggested for in situ measurements on the Martian surface; these analyses in combination with spectral and chemical data would enable even more precise identification of the types or classes of minerals present on Mars.

Iron Oxide Mineralogy: A number of laboratory studies and projects involving interpretation of spectral observations from Mars have suggested that iron oxides/oxyhydroxides are present in the surface material and likely exhibit a broad range of crystallinities from nanophase to a few microns in size. These are distinct from the bulk, gray hematite deposit observed by TES in *Sinus Meridiani* [1]. Understanding the magnetic properties of these iron oxides/oxyhydroxides and their mineral structures will provide abundant information about the geochemical processes that have taken place on the surface or near-surface of the planet.

Ferrihydrite is a nanophase ferric oxyhydroxide mineral that frequently forms in aqueous terrestrial environments and may have formed on Mars if water was present. However, ferrihydrite would be unstable on the surface of Mars today. Depending on the temperature, redox conditions, amount of water and pH, ferrihydrite converts to magnetite, maghemite, goethite or hematite [e.g. 2,3]. Identification of these minerals on Mars would therefore provide constraints on a number of environmental factors.

Shown in Figures 1 and 2 are reflectance spectra that indicate structural changes in ferrihydrite through alteration. Changes are observed in the optical bands due to iron excitational modes and in the NIR and mid-IR due to vibrational modes. These spectral features could be observed remotely on Mars given sufficient spectral and spatial resolution.

Figure 1 Visible/Near-Infrared Reflectance Spectra of Ferrihydrite and Altered Ferrihydrites.

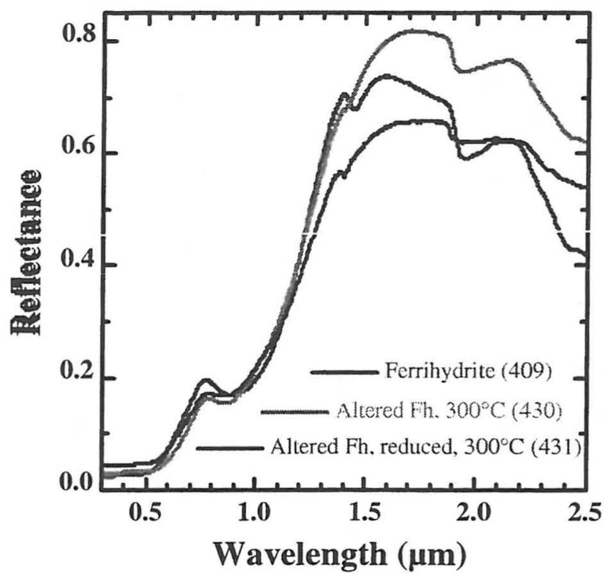
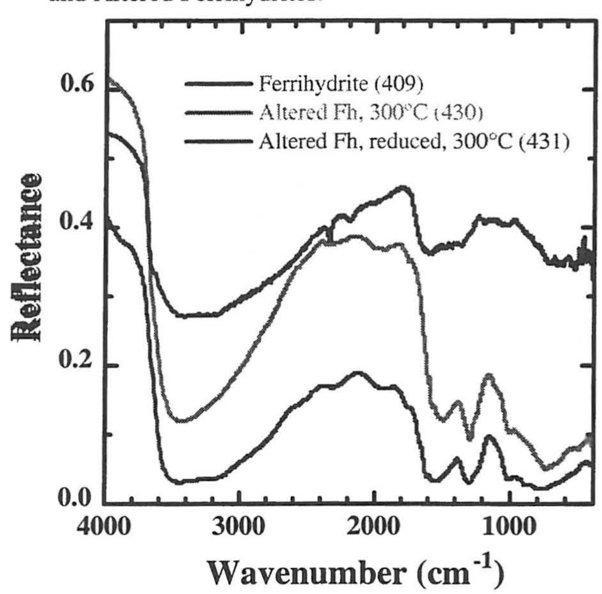


Figure 2 Infrared Reflectance Spectra of Ferrihydrite and Altered Ferrihydrites.



Crystalline *vs.* Amorphous Silica: Identification of crystalline alteration minerals on Mars would imply the presence of more water than would the presence of amorphous silicate grains. Alteration of basaltic tephra/ash in volcanic systems has shown that environmental conditions, such as the abundance of water, play a dominant role in the formation of clay minerals [e.g. 4,5]. For example, smectites typically form in low moisture conditions, while kaolinites typically form in high moisture conditions. Ultra dry environments or short-term alteration histories may support only the formation of amorphous or poorly crystalline silicates.

Figure 3 Visible/Near-Infrared Reflectance Spectra of the Sulfate Minerals Jarosite and Alunite.

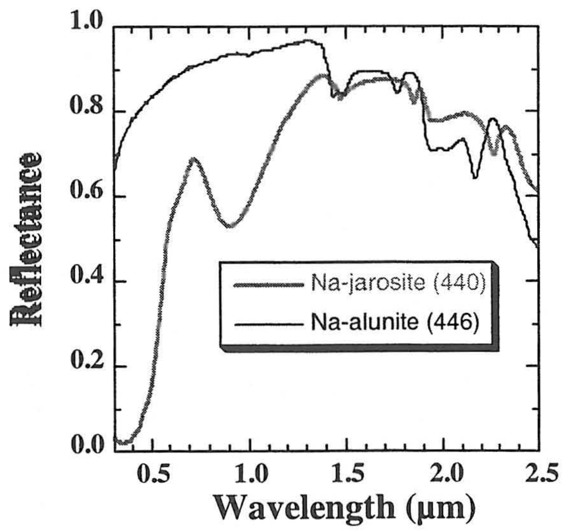
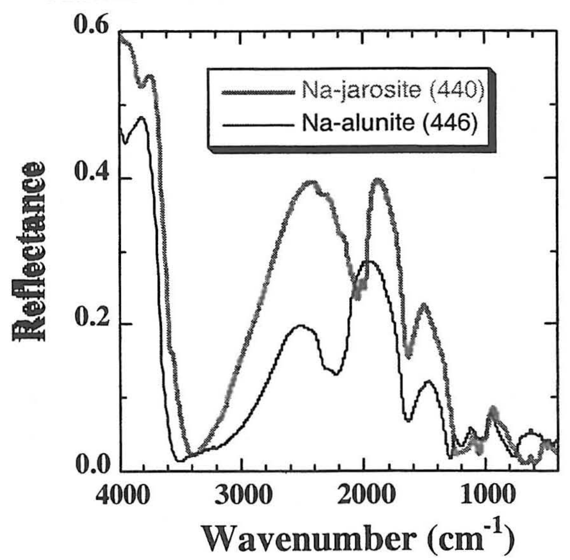


Figure 4 Infrared Reflectance Spectra of the Sulfate Minerals Jarosite and Alunite.



Sulfate Minerals or Salts: Identification of crystalline sulfate minerals on Mars may indicate hydrothermal alteration in the presence of sulfate fumes. Other potential sources of sulfates on Mars include evaporite deposits. Both of these situations involve minerals that could be identified using near-infrared (and maybe thermal infrared) spectroscopy [e.g.4,5] and represent sites of interesting geologic processes worthy of consideration for additional measurements on a lander/rover mission and/or sample return. Shown in Figures 3 and 4 are reflectance spectra of jarosite and alunite as examples of possible sulfate minerals that could be identified on Mars.

Implications for Astrobiology. The mineral maghemite (γ-Fe_2O_3) is thought to be one of the magnetic components in the Martian surface material [6,7]; however, it is a rare mineral on the Earth and requires a reducing agent for synthesis [e.g. 2]. Organic material serves as a reductant in maghemite formation during forest fires on Earth [8] and may play an important role in maghemite formation on Mars as well. Studies are currently underway to compare magnetite, mag-hemite and hematite formation from ferrihydrite under Martian environmental conditions.

Developing a mechanism for maghemite formation from ferrihydrite or goethite on Mars could link the maghemite thought to be present throughout much of the surface material with water and biology. Finding evidence for higher concentrations of maghemite on the surface of Mars would mark locations for further study, including searching for organics and components of interest to Astrobiology. Coarse-grained hematite was identified in *Sinus Meridiani* (~0-3 °S, 2-7 °W) on Mars by TES [1]. This region on Mars appears to be unique and is of great interest to Astrobiology. Nanophase iron oxides/oxyhydroxides such as dehydrated ferrihydrite, hematite, magnetite and maghemite may be present here as well and should be investigated.

References: [1] Christensen P. et al. (2000) *JGR, 105,* 9623-9642. [2] Cornell R. M. and Schwertmann U. (1996) *The Iron Oxides*, VCH, New York. [3] Bishop J. L. et al. (2000) *LPS XXXI,* CD-ROM# 1946. [4] Bishop J. L. et al. (1998) JGR , *103,* 31457-31476. [5] Bishop J. L. et al. (2000) *LPS XXXI,* CD-ROM# 1874. [6] Hviid S. F., et al. (1997) *Science, 278,* 1768-1770. [7] Madsen M. et al. (1999) *JGR, 104,* 8761-8779. [8] Campbell A. et al. (1997) *Clay Miner. 32,* 615-622.

How to Access and Sample the Deep Subsurface of Mars. J. Blacic, D. Dreesen, T. Mockler[1] and G. Briggs [2]

[1]Los Alamos National Laboratory,MS D443, Los Alamos, NM 87545, jblacic@lanl.gov, [2] Center for Mars Exploration, NASA Ames Research Center, 239-20, Moffett Field, California 94035, gbriggs@mail.arc.nasa.gov

We are developing a technology roadmap to support a series of Mars lander missions aimed at successively deeper and more comprehensive explorations of the Martian subsurface. The proposed mission sequence is outlined in the table below. Key to this approach is development of a drilling and sampling technology robust and flexible enough to successfully penetrate the presently unknown subsurface geology and structure. Martian environmental conditions, mission constraints of power and mass and a requirement for a high degree of automation all limit applicability of many proven terrestrial drilling technologies. Planetary protection and bioscience objectives further complicate selection of candidate systems. Nevertheless, recent advances in drilling technologies for the oil & gas, mining, underground utility and other specialty drilling industries convinces us that it will be possible to meet science and operational objectives of Mars subsurface exploration.

Building on results from three workshops that have examined the objectives and context of deep subsurface sampling on Mars, we are currently performing a preliminary engineering systems analysis of technologies for

Mission	Science Objectives	Operational Objectives
Near-Surface Recon Explorer **(1-5m depth)** →	characterize near-surface materials (cuttings samples - min/pet, geochem) geophysical sensing of subsurface (seismic array, GPR, gravity)	explore multiple landing sites --1km-range rover, long-duration instruments - build geophys. network demo return to base for sample analysis and vehicle recharge remote control & mobility demo
Shallow Subsurface Explorer **(200m depth)** →	characterization of shallow subsurface (core samples, 1st look for organics) expanded geophysical sensing (heat flow array)	point landing at one of surface sites demo partial autonomous drilling demo hole stabilization demo core sample handling demo instrumented completion
Deep Subsurface Hydrosphere Explorer **(4000m depth)** →	sample deep hydrosphere search for biosphere expanded core analysis expanded geophysical sensing validate geophysical models with samples	point landing at shallow site demo autonomous deep sampling demo well pressure control
Water Production **(4000m depth)** →	produce water & other resources (heat, methane, salts)	demonstrate production well completion & operation (5cm diameter) demonstrate resource handling/storage/processing

the ***Shallow Subsurface Explorer*** mission. This proposed mission seeks to penetrate up to 200m to acquire core samples, make geologic and geophysical measurements and function as a technology test bed for the system elements that will be needed for the more difficult deep sampling mission. In the analysis, we have identified 36 distinct drilling technologies that we considered might be applicable to this mission. Working from workshop studies yielding agreed upon constraints of mass and power and the probable shallow subsurface geologic environment, we have eliminated all but ten of these systems on first order considerations. For example, systems requiring hydrous drilling muds were eliminated on the basis of mass, contamination of samples and Mars surface temperature and pressure conditions. On the other hand, systems that can use compressed Martian atmosphere as a drilling fluid for cooling and cuttings conveyance have been retained for further analysis. This reduced list of credible systems will be analyzed in greater detail to select down to a list of 3-5 systems recommended for engineering development, terrestrial field testing and comparison. We expect a best system to emerge out of this phase for flight development.

A follow-on mission is proposed to penetrate 3-5km below Mars surface to intersect a putative hydrosphere, take samples and search for possible extant life. We hope to have learned much, both scientifically and operationally, from previous missions to make this difficult task possible. We expect to encounter additional problems of hole stability and well control related to possible geopressured zones or clathrate horizons. Similar problems are dealt with every day in terrestrial drilling, so we are confident that they can be over come on Mars if sufficient resources are available.

Concepts and Approaches for Mars Exploration
July 18, 2000
Houston, Texas

Submitted by Richard Blackmer
MTI
Private Sector
blackmer@mosquitonet.com

Getting to Mars to Stay

This abstract describes a proposal to start building a Mars Transportation Infrastructure, **MTI,** starting in earth orbit. The first facility at Mars should be the Manned Mars Orbiting Station, **MMOS**.

====================

Terms defined:
MTI - Mars Transportation Infrastructure

The hardware components of the **MTI** are:
MMOS - Manned Mars Orbiting Station
EMAS - Earth-Mars Assembly Station
MTS - Mars Transfer Shuttle
MSL - Mars Surface Lander

Premise:

Sending a human mission to land on Mars, and to return couple of years later accomplishes little, is wasteful of resources, creates nothing of lasting value, is horribly expensive, and is not necessary in the near future. The superior plan is to build permanent facilities.

The first manned facility at Mars should be in orbit, not on the surface. Mars should be observed for a period of time from medium Mars orbit by human beings in a permanent orbiting base, **MMOS,** while the complete **MTI** is being built.

Background:

In the time since Viking I landed at Chryse Planitia July 20, 1976, a career-spanning 24 years ago, plans implemented by NASA for exploration and development of this new world have been anything but robust. Several scientific probes have been sent, a few have been wildly successful. Mars Global Surveyor is certainly in this category. NEAR Shoemaker (Near Earth Asteroid Rendezvous,) orbiting Eros at a walking pace, although not sent to Mars, must be mentioned as a forerunner of **MMOS**. Much should be happening at Mars besides 99% duplicating the Viking missions over and over. It is past time to begin the work of developing a Mars-oriented facility for human transportation and habitation.

Category:

Of the three categories suggested for working groups, **Architectures** seems closest for this proposal.

Mars Transportation Infrastructure:

It is intended that **MMOS** be built in stages just as the International Space Station, **ISS,** is being built, but quicker and cheaper if the private sector does the work. These are the stages of construction of the **MTI**:

1. Build **MMOS**. Begin transferring the modules to Mars. It might help to have **EMAS** in earth orbit, perhaps loosely associated with **ISS**, to act as an intermediate assembly and test facility for **MMOS** components.

2. Then build one or more human-rated **MTS** that will pass back and forth between **EMAS** and **MMOS**. Plan to use the Mars Transfer Shuttles for many years with refurbishment and refueling at **EMAS** and later at **MMOS**.

3. Later, but not last, build one or more human-rated **MSL**, that will shuttle from **MMOS** to the Martian surface and back.

4. Last, if it seems interesting to do so, a manned base or settlement can be built on the surface of Mars itself.

MTI should be a robust set of stations and vehicles that reduces the hazard of travel between planets, reduces the cost per trip, and allows frequent and nearly continuous transportation opportunities to and from Mars.

MMOS can be placed on a moon, Phobos for example, or it can be in its own orbit. Advantages of having a good amount of mass at hand are many when considering human habitation:
cheap radiation shielding;
plentiful construction material;
small gravity field;
stable observation platform;
visual object that can be seen at immense distances;
no need to land humans on Mars right away;
efficient fuel use while building **MMOS** and **MTS**;
Mars samples can be brought up automatically to the station and analyzed there once the **MMOS** is occupied by an appropriate scientist, rather than bringing them all the way back to Houston.

The moon for practice:

A similar system, the Lunar Transportation Infrastructure - **LTI**, could be used to return to the moon. In fact, the moon could have a Manned Lunar Orbiting Station - **MLOS** without worrying about landing and returning like Apollo,

This could have been done long ago, but might done first as practice before building the **MMOS;** it could easily, quickly, and inexpensively be done.

Mir would be good in this capacity - send it into lunar orbit rather than waste it in a couple years.

A Lunar Transfer Shuttle - **LTS** would be wanted soon to carry humans and equipment back and forth from the **ISS** to the **MLOS/Mir**.

Mars Micromissions using the ASAP-5 platform (Ariane 5).

Jacques-Emile Blamont, Jean-Louis Counil, Centre National D'Etudes Spatiales, 2 place Maurice Quentin 75039 Paris Cedex 01 France, (Jacques.Blamont@cnes.fr, Jean-Louis Counil@cnes.fr).

Introduction: After a brief description of the concept, a number of missions of interest to the French scientific community will be presented using mobile (balloons, rovers) or fixed stations (magnetic, atmospheric, mineralogy and electromagnetic sounding).

The piggyback Ariane-5 concept

The paper *Exploring Mars with left rovers* to this symposium by G.R. Wilson, S.E. Matousek, K.O. Leshly, J.R. Willis, J. Blamont, C. Cazaux explains the principle of the Martian piggyback system using the Ariane-5 ASAP configuration.

The Martian piggyback is placed on a geostationary transfer orbit (200 x 36,000 km) with the help of the commercial launch of a geostationary telecommunications satellite. The • • requirement for reaching Mars from GTO is of the order of magnitude 1.6 to 1.8 km s^{-1} . Therefore the spacecraft has to carry the necessary quantity of fuel (40% of the available mass). The total available mass is 240 kg. According to the study performed for JPL by Ball Aerospace, the capability for a Mars reentry probe varies from 40 to 60 kg and the capability for a payload placed on a Martian orbiter 10 to 60 kg for the 2005 to 2009 launch windows.

Various scientific proposals discussed by CNES

During the major strategy symposium organized by the French Space Agency CNES in Arcachon, France (March 9-12, 1998) a number of scientific missions based on the Ariane piggyback concept were described and supported by the French scientific community.

For instance, the so-called *Dynamo* experiment would be a satellite of Mars devoted to the cartography of the crustal magnetic field and simultaneously to the physico-chemical caracterization of the neutral and ionized atmosphere above 15 km of altitude. This would be the first step of the deployment of an environmental survey of the red planet, pursued by subsequent missions devoted to the understanding of the interaction between dynamics (general circulation, gravity waves) and physico-chemistry (aerosols and clouds).

Another satellite experiment would be the *Kelvin* proposal for the global vertical sounding of the temperature of the atmosphere with a microwave instrument. This operation would be complemented by the *Pascal* network (see below).

A second category of researches made possible by the concept is the deployment of networks. An example is the *Pascal* proposal (in cooperation with Ames Research Center) for global meteorology, (24 sites) which would measure temperature, pressure and dust density for ten Mars years, define the variability of the Martian global climate, and characterize Martian weather for future human exploration. Another network (2 stations) would determine the structure of water reservoirs, the mass of water stored and the existence of liquid water by using seismic active topography as well as magneto telluric sounding.

A third category of uses of the piggyback concept is the direct deployment in the atmosphere of several various vehicles like balloons and airplanes. An airplane launched on a pigyyback probe could fly for 30 minutes with a 1,5 payload. A fleet of gliders, each of them with a life time of 15 minutes would provide on a number of sites along the *Valles Marineris* canyon the vertical mineralogical structure of the strata observed on the cliffs, by *MGS*. A balloon can fly ten days and carry a 5 kg payload. CNES did develop during the 1990-1994 time frame the technology of Martian balloons. In particular, an attractive idea would be to map the crustal magnetic field from a balloon, which may be the best way to obtain a high-resolution map of the linearities of the field. This would be an optimized grouping of ideas : piggyback, balloon, instrumentation for a first class science objective.

A fourth category is the deployment of various rovers. In particular the inflatable rovers, studied in 1979-1982 by CNES and resurrected at JPL could have a mass inferior to 20 kg. It could carry a 20 kg payload over hundreds of kilometers (mineralogy, chemistry, instruments). Such rovers could be deployed by the means of solar montgolfieres of the type developed by CNES for atmospheric research on Earth.

All the above mentioned experiments will be described in detail.

SCOUTS: USING NUMBERS TO EXPLORE MARS IN SITU. D. L. Blaney and G. R. Wilson, Jet Propulsion Laboratory, 4800 Oak Grove Dr., MS 183-501, Pasadena, CA 91009, Diana.Blaney@jpl.nasa.gov and Gregory.R.Wilson@jpl.nasa.gov

Introduction: Mars is a planet with a complex geologic history involving fluvial, volcanic, aeolian, atmospheric, and impact processes. Many critical question about Mars are still heatedly debated within the scientific community and we still have much to discover.

The current Mars exploration philosophy involves remote observation of the planet from orbit and intensive in situ study of a few sites on the surface. Orbital data provides a global picture while in situ investigations provide detailed knowledge at a single location.

Mars Scouts are proposed to provide access to multiple locations on Mars. They address the emerging program needs of exploring the diversity of the planet globally in ways that cannot be achieved from orbit. The goal of the Scout is to find a way to investigate many locations on the surface of Mars in an affordable and efficient manner. We have only visited three locations on the surface of Mars, which have very similar characteristics. Increased numbers allows more types of locations to be investigated.

The hallmarks of Scouts are numbers and access. Thus the capability of a single Scout will be limited. The science return from a single Scout will be significantly less than from a large science lander or an orbiting spacecraft. Scouts rely on their numbers to collectively provide a substantial increase in our knowledge of Mars.

Scouts potentially serve two purposes in the Mars exploration architecture. First, Scouts are a science exploration tool. They provide access to places on Mars we currently can't explore because program focus, surface roughness, elevation, or latitude that we know are scientifically interesting. Scouts can react to new discoveries and evolving ideas about Mars. They can be used to test theories which until proven would not warrant the investment of a large lander.

Second, Scouts enable better large scale missions by providing ground truth of remote sensing data and allowing us to "know" sites in advance before sending large landers and sample return missions. This increases the probability of success for these expensive missions both from safety and science return standpoints.

Genesis of Scouts and Disclaimer: The Scouting concept arose during the re-architecture activities starting in January of 2000 and is continuing to be developed. The ideas presented here have benefited from discussion and recommendations from several external groups and JPL studies that are listed. These groups did not always reach a unanimous agreement about what Scouts are or need to be. They also did not always agree with each other, and members of these groups or the groups themselves may not agree with the vision for Scouts presented in this abstract.

Acknowledgements and Thanks to:

Mars Peer Review Group Global and In Situ Studies Team: Ray Arvidson, Bruce Banerdt, Jim Bell, Geoff Briggs, James Cutts, Phil Christensen, Jack Farmer, Paul Falkowski, Matt Golombek, Ron Greeley, Bob Haberle, Laurie Leshin, Frank Palluconi, Jeff Plaut, Steve Saunders, Sue Smrekar, Jeff Taylor, Aaron Zent, and Rich Zurek

2003 Scout Science Instrument Definition Team: Scott Murchie (chair), Bruce Banerdt, Jeff Barnes, Dan Britt, Todd Clancy, Alan Delamere, Dave Glenar, Trude King, Jeff Moersch, Alan Treiman, Jim Garvin (ex-officio), Cathy Weitz (ex-officio) and Bruce Betts (ex-officio).

Scout Feasibility Study: Sarah Gavitt, Study Manager, Sue Smrekar Study Scientist

2003 Scout Study: Barry Goldstein, Study Manager

2005 Scout Study: Sylvia Miller, Study Manager

And those many individuals who participated in the various incarnations of Scout studies and brainstorming sessions over the last six months!

Possible Implementations of Scouts: What Scouts can be will depend on the science goals, the technology ready for use, and the resources available to be spent on Scouts. Soft landers, hard landers, small rovers, penetrators, gliders, airplanes, and balloons have all been discussed as possible Scouts implementations. Each platform has strengths and weaknesses which tie in with specific science objectives. From a Scout perspective, they share a similar thread because they try to address focussed scientific questions which require in situ measurements from multiple locations. Mars Scouts in the broadest sense can be thought of not as specific scientific platform but as an exploration philosophy whose purpose is to provided increased scientific access to the Martian surface.

An Example, The 2003 Scout Lander: Most of the detailed engineering and mission design work on Scouts done this winter and spring focussed on Scouts for 2003. These Scouts were delivered as a piggyback payload on a lander or an orbiter. Numbers were small 1-2, making these Scouts precursors to a future dedicated Scout mission. The extreme schedule constraints of a 2003 launch, made the choice of a soft lander most reasonable from a technology readiness / risk perspective.

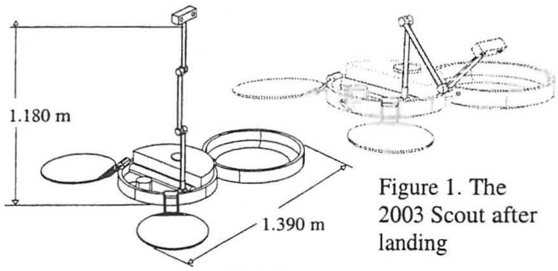


Figure 1. The 2003 Scout after landing

Entry descent and landing was accomplished using a de-orbit stage (for the orbiter option) and Viking/Pathfinder heritage aeroshells and super-sonic parachutes. A balloon was used as a decelerator to further lower the impact speed. Pathfinder heritage airbags were used to cushion the impact. At impact the balloon was cut away and the landed Scout rolled to a stop, retracted it's airbags, and deployed it's solar panels and mast (see Figure 1). For the de-orbited case, Scouts had an error ellipse of < 80 km and example mission designs had Scouts targeted to any latitude.

The science goals of the 2003 Scouts were focussed on the identification of aqueous mineral deposits, which is tied directly to the Surveyor program mantra of "Follow the Water". Table 1 show the reference instrument suite and the expected science return from the 2003 Scouts.

Data from the 2003 Scouts would have enabled a better Mars sample return mission in the future by making sure that the sample was scientifically interesting and the type of terrain was safe for a large sample return lander. Orbital remote sensing data would be validated, letting what was learned at the Scout site be extrapolated to other regions.

However, in addition, the 2003 Scouts were designed to go almost anywhere on Mars. They could land at elevations < 4 km (Viking reference) and at any latitude, if the season was correct. This provided access to places on Mars such as the southern highlands, the interior layered deposits of Valles Marineris, and the polar layered deposits. Thus these Scouts would supplement the core, larger lander portion of the program by permitting the choice of landing site to be driven by scientific interest.

Challenges of a successful Scout program: Implementing Scouts to achieve the science return, numbers, and access will face many challenges. Scientifically, we are starved for in-depth scientific investigations on the Martian surface. There will be an ever increasing appetite to make Scouts keep on doing more and more, until they evolve into more capable spacecraft. This will decrease the numbers we can send, and Scouts will morph into small landers. Scouts also require innovative engineering and management practices. To make Scouts affordable, we must find ways to reduce the recurring cost of each Scout unit. Simplification of engineering sub-systems is critical because to achieve numbers envisioned, Scouts must be as lightweight as possible. However, if achieved, Scouts would provide a powerful new tool in Mars explorations.

Table 1. The 2003 Scout Reference Payload and Science Goals

Instrument	Description	Science Goals
Descent Imager	1024x1024 CCD, 10 m to < 10 cm, 90°FOV, 500 K pixel/sec readout	Determine how landforms changed with spatial scale and link orbital imaging data sets Provide geologic context of the landing site Determine the nature of rock hazards
Stereo Color Imager	Two 1024x1024 CCD cameras separated by 10 cm. < 0.8 µrad IFOV, 8 color filter wheel. depth of field is 1.3m to ∞. Close up lens with ~60 µm / pixel.	Determine the rock and soil diversity at the site Provide geologic context and landing site location information Measure rock size distribution and slopes for hazards Look at soil and rocks near lander to study texture and determine if rock fragments are present in soil
Near Infrared Spectrograph	Miniature convex grating spectrometer covering a single octave, 1.2-2.4 µm, 2x8 mrad FOV, extended InGaAs 512 line array, 5 nm resolution	Determine the mineralogy (especially pyroxene, clays, and carbonates) of representative rocks and soils targeted based on color imaging data Validate surface mineralogy determined from orbit
Engineering Sensors for Mars Environmental Investigation	IMU, pressure and temperature sensors	Atmospheric structure and winds during entry and descent Landed pressure and temperature monitoring

THE ADAPTATION OF TERRESTRIAL MINING EXPLORATION DRILLING TECHNOLOGY TO SPACE. Dale S. Boucher[1], Northern Centre for Advanced Technology Inc. (NORCAT), 1400 Barrydowne Rd., Sudbury, Ontario, Canada, P3A 3V8, e-mail: dboucher@norcat.org.

Introduction: NORCAT has formed a coalition with a group of mining equipment manufacturers located in Sudbury, Ontario, Canada, to develop an autonomous mining exploration tool for the purpose of drilling and sample core retrieval. This group intends to develop a unit that can be readily adapted to both terrestrial and extra-terrestrial applications.

The approach is to develop a terrestrial unit first, followed closely by a "standard" unit for space based applications such as Asteroid prospecting, Mars and Lunar sample returns, etc. This paper provides an update as to project progress and raises some specific issues related to further development work.

Background: Exploration style drilling is used in the mining industry for the purposes of determining ore reserves and the delineation of new and existing ore bodies. It is based on core sample extraction and retrieval from various depth bore holes. This project focuses on medium depth (500 metre) core drilling.

The initial system design and much of the initial work was performed using a standard Size A diamond drill system. Operational specifications [1] are:

Parameter	Value (nom.)	Units
Hole Depth (up or down)	600	metre
Hole Diameter	48	mm
Core diameter	27	mm
Bit Rotation Torque	1,750	joules
Bit Rotation Velocity	1,300	RPM
Axial Thrust at bit	35,500	Newton
Axial Rate of Penetration	250	mm/min.

Base Technology: The base technology for this project was selected as the result of two primary points of consideration; first, the Background Intellectual Property (BIP) representative in the coalition partners, and second, the potential for application in BOTH space and terrestrial commercial sectors. Terrestrial commercialization requires the use of COTS products wherever possible, to facilitate design and improve margins. This quickly became a guiding principle to design efforts by the coalition.

Hole Propagation: Earlier work [2], [3] established diamond drilling technology as the technology of choice. The decision was primarily based upon a few salient points: 1) energy conversion is one of the highest in the industry, 2) post propagation hole stabilization and core sampling are inherent in the technology, 3) hole diameters can be tightly controlled, 4) the technology is readily and dynamically adaptable to varying ground conditions, 5) reactive forces are among the lowest of the contact drilling methods, and 6) the makeup of the coalition, within which a vast wealth of experience and BIP in diamond drilling was represented.

Prime Mover: Existing diamond drill units utilize electro-hydraulic or mechanical hydraulic drives. Since the coalition has vast experience in harsh environment electric DC drives, and MIL spec communications and control packages, it was determined early on that the new drill would use only electrical power for set-up, deployment, and operation.

The decision was also based upon the experiences gained by the coalition as relates to the maintenance requirements of underground hydraulic systems and their poor MTBF. Hydraulics systems generally require the use of cooling systems to remove waste heat. This required the installation and maintenance of significant infrastructure and logistic support. It was essential that any unit developed exhibit high reliability, require low maintenance, exhibit long operation life times and be capable of operation in hypo-baric conditions. This precluded the use of hydraulics.

Mechanical Stabilization: Existing exploration drill systems require careful alignment and set-up to ensure proper drill hole propagation. Although existing terrestrial exploration drills can weigh in excess of 5 tonnes, they still require the use of a manual anchoring procedure to ensure the unit is stationary and stable during drilling operations. This is normally accomplished via the placement of a resin activated anchor or a rock bolt to hold the drill firmly in place during the drilling operation. The operator must then re-align the drill to the proper azimuth and dip, and begin to drill, allowing the anchor to absorb reaction forces.

Work was started on a self deploying anchor system capable of withstanding drilling reaction forces. DMC Drilling Supplies has a patent pending for such a device for use in terrestrial mining applications.

System Control : Control of drill parameters during the drilling phase is paramount to the extension of drill bit and rod life as well as to the prevention of unwanted excursions of the drill, especially during drilling media transitions.

Work was performed by NORCAT and DMC Drilling to develop and refine the appropriate parameter control algorithms. DMC Drilling is now marketing the system under the product name Smart Drill as a retro-fit kit for existing hydraulic exploration drills.

Rod and Core Handling: To date, fully autonomous drilling has been limited to approximately 10 metres; the limiting factors being rod handling, and core handling.

Standard mining automation techniques have been used to develop an automated rod handler system, capable of tripping rods autonomously. Such a device is presently in pre-market testing.

Core retrieval methods are actively being worked at by a number of equipment suppliers in the Sudbury region, as well as by some major mining companies, as part of overall mining automation programs.

The Next Steps: The coalition has identified key steps in this development program and has organized them into a planned approach. Each step has been shown to have potential commercialization activities in terrestrial mining and exploration

Electric Drill: The coalition is not aware of any production scale exploration drill available on the market that is fully electric. The first effort is to develop and prove a commercially viable all electric drill capable of drilling and coring to a depth of 500 metres in various types of ground..

Efforts are underway to develop an A size compatible unit capable of matching the specifications of existing hydraulic units [1]. Once completed, the unit will be installed at NORCAT facilities for comparative testing with the existing A-size unit.

Control algorithms developed for the hydraulic unit will be migrated to the electric drill and the control package simplified and miniaturized.

Anchoring System: The existing self-deploying anchor system will be used as the final stage anchor for all terrestrial and extra-terrestrial units. Work is already planned to develop primary anchoring [3] technology for micro-gravity environs.

Drill Bit: Existing diamond drill bits require water flushing to remove balings, lubricate the diamond matrix/rock interface, and dissipate heat. Efforts are underway to develop a diamond drill bit capable of drilling dry and enabling mechanical removal of balings during drilling.

The miniaturization of the drill unit would require a redesign of the drill bit itself, so that maximum penetration could be realized while reducing balings production. Since in-situ analysis is not yet a reality on a commercial scale, adequately sized core samples must be produced that are of use to geologists and others interested in using this technology for sample analysis. These criteria will drive the final configuration and design of the drill bit. Work has already been started on specialty drill bit design by coalition members.

Rod Handling: Standard length drill rods (A size) are 1.5 metres long, hollow to allow core retrieval without drill bit removal, and can be joined together with simple threading algorithms. During drilling operations, the drill rod is used to transfer rotational energy as well as thrust to the drill bit. The drill rod serves to stabilize the drill hole post propagation and can be used as a guide for later analyses such as in-situ geophysical testing, or resource extraction [3], [4].

The vagaries of autonomous drilling operations have shown that rod coupling is the weakest point of the system. In addition, shipping and storage of drill rods is a significant issue. Work is well under way to address the issue of autonomous rod handling and storage.

Sample Core Handling and Recovery: Core samples are presently recovered once every 10 metres maximum. Nominally, they are recovered once per 1.5 metres, or upon operator intervention. The criteria for core recovery are excessive system loading on the drive components of the drill (rotational or thrust) such that a potential stall occurs, or the bit ceases penetration. Core recovery is presently handled semi-autonomously and cores are catalogued and stored by an operator for later analysis. An autonomous unit must be capable of performing these tasks efficiently, accurately and repetitively. No work has been performed in this area as yet.

Space Drilling: Preliminary performance specifications for the "Space Drill" are for an all-electric drill capable of autonomously deploying and anchoring in a micro-gravity, airless environment and extracting core samples 10 mm diameter to depths of 100 metres. The technology is intended as "Throw Away", using COTS products where possible. It is also intended as a dynamically reconfigurable system to allow piggy back science missions to ride along, such as in hole seismic sensors, radio beacons, analysis, etc. The coalition has developed some conceptual models based upon the SpaceDev Micro-NEAP project. The system will be prototyped at NORCAT facilities and then integrated and tested at the NORCAT mine in hard rock under 2-D micro-gravity simulation and extreme temperatures.

Acknowledgements: Coalition: NORCAT, DMC Drilling Supplies Ltd., Electric Vehicle Controllers Ltd., Falter Engineering Inc, Sudbury; SpaceDev, California

References: [1] Longyear Australia Pty Ltd., *Longyear LM 75 Operations and Service Manual.* [2]D.S. Boucher (1997) *Alternative Exploration Drilling Technologies, Laser and Water Based Drills for DMC Drilling Supplies Ltd.*. [3] Mark J. Sonter (1997) *The Technical and Economic Feasibility of Mining the Near Earth Asteroids.* [4] D.L. Kuck (1992) *In-Situ Recovery of Water from Dormant Comet Cores and Carbonaceous Chondrites, Space '92*

APPLICABILITY OF THE MARS POLAR LANDER TEGA INSTRUMENT TO FUTURE MARS MISSIONS.

William V. Boynton[1], Samuel H. Bailey[1], David K. Hamara[1], Michael S. Williams[1], Rolfe C. Bode[1], Michael R. Fitzgibbon[1], WenJeng Ko[1], Michael G. Ward[1], K. R. Sridhar[1], Jeff A. Blanchard[1], Ralph D. Lorenz[1], Randy D. May[2], David A. Paige[3], Asmin V. Pathare[3], David A. Kring[1], Laurie A. Leshin[4], Douglas W. Ming[5], Aaron P. Zent[6], D. C. Golden[5], Kristopher E. Kerry[1], H. Vern Lauer, Jr. [5], Richard C. Quinn[6]

Introduction: This work will describe the TEGA instrument as it was built for the Mars Polar Lander mission, its applicability to future Mars missions, and modest modifications which can make it more valuable to the future exploration of Mars.

Science Objectives: The main science objectives of TEGA were to determine the abundances of the two most important volatile compounds in the Martian soil, water and carbon dioxide, and the minerals or phases with which they are associated. In addition, TEGA would have measured the isotopic ratio of carbon in the carbon dioxide and constrained the amount and nature of the putative strong oxidant found in the Martian soil by Viking. The instrument was designed to be especially useful to help us understand the polar layered deposits At the present time, we have few constraints on the origin and evolution of these deposits. TEGA analyses would have provided a first-order view of the amount of water and carbon dioxide in the uppermost layers of the deposit at the landing site, as well as their variations in composition to a depth of 0.5 meters below the surface.

Instrument Description: The instrument (figure 1) is composed of a set of eight thermal analyzers, each of which can be used only once. Each analyzer includes a cylindrical nickel sample oven, about 1cm long and 2mm diameter (inside), and an identical reference oven. After the sample is acquired and the ovens sealed, the ovens are ramped up in temperature at a controlled rate by digitally modulating the power supplied to the oven heaters. Comparing the power required to maintain this rate on the sample oven with that for the reference allows the heat capacity of the sample and the enthalpies associated with any phase transitions to be determined.

Nitrogen gas is flowed at a controlled rate through the ovens to sweep away any evolved gas to the EGA -- an yttria-doped zirconia amperometric cell (for O_2) and a tunable diode laser (TDL) absorption spectrometer (for H_2O and CO_2). The TDL spectrometer provides for the detection of water vapor and carbon dioxide in a small mirrored Herriott cell, which gives a 1-m pathlength in a 5-cm-long cylinder. It has two laser diodes (one for water, one for CO_2), which are scanned in wavelength across an absorption band, allowing the quantitative determination of the amount of gas released and its isotopic composition.

The combination of DSC and EGA is particularly powerful, since volatile release can be characterized in a correlated way by both components.

Instrument Performance: The performance of the instrument was studied extensively before launch. It is able to detect very small amounts of water and carbon dioxide as shown in Table 1. We had some difficulty with the TDL spectrometers which is well understood and would be corrected for reflight which would increase the precision of the CO_2 isotopic ratio by about a factor of 5.

Table 1. Detection limit with TEGA as flown

Parameter	Absolute	Fraction
Ice (calorimetry)	0.05 mg	0.2 %
$CaCO_3$ (calorimetry)	0.14 mg	0.5 %
Water (vapor)	1 μbar	8 ppm
CO_2 (vapor)	15 μbar	0.03 %
CO_2 (isotopic ratio)	± 0.6% (precision)	

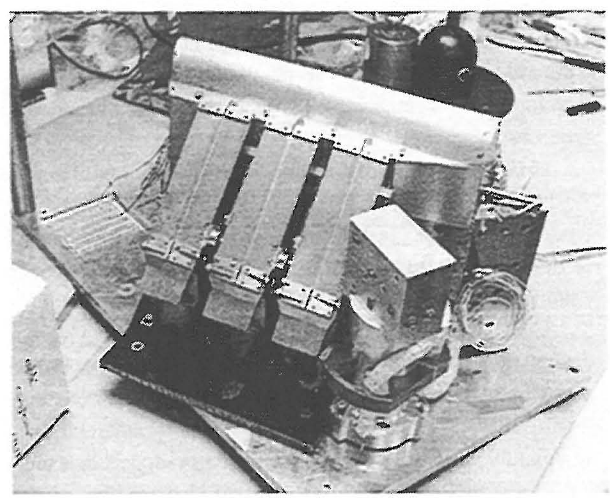


Fig.1 *The flight model TEGA instrument. The angled rectangular structures are three of the eight thermal analyzers (the remaining five are on the opposite side). Each analyzer has a sample funnel with an agitator, a sample and reference oven, an oven closing mechanism, and a set of doors to prevent contamination via airborne dust or unintentional spillage from the robotic arm scoop. The box and cylinder at right contains the Herriott gas absorption cell with the two laser diodes and detectors in the box. The section between the two banks of analyzers, with the rounded top, contains the carrier (purge) gas and calibration gas tanks, the gas handling manifold and the oxygen cell.*

Relationship of TEGA to objectives of future Missions. Understanding the reservoirs of H_2O ancd CO_2 is an essential aspect of future Mars exploration. Even though TEGA was designed for a polar site, it is very appropriate for addressing important objectives at other sites.

One of the potential soil reservoirs of water is ice, and TEGA is well designed to determine the ice content in the layered terrain. This is a very important reservoir, and will probably never be understood without another lander mission to visit a polar site.

Another important potential reservoir is the collection of minerals that comprise the Martian soils. Analysis of the volatile content of Martian soils, with knowledge of the phases in which the volatiles reside, will provide significant tests of hypotheses concerning past climate on Mars. If the soils contain crystalline clay minerals and abundant carbonates, it will suggest a past climate in which water was present for long periods. On the other hand, poorly crystalline clay minerals with little carbonate would indicate only brief periods of water interactions. This important objective can be satisfied with a landing at any site, whether polar or not.

In addition to ice and chemically combined volatiles, there may be other sites in the soils for adsorbed volatiles. Published estimates for the sizes of the adsorbed H_2O and CO_2 reservoirs vary widely due to uncertainties in the adsorptive properties of the regolith materials, their physical states, and the extent of the regolith itself [*Carr*, 1986; *Fanale and Cannon*, 1971; *Fanale et al.*, 1982; *Clifford*, 1984]. However, most workers agree that the present Martian inventory of H_2O and CO_2 probably exceeds the present atmospheric inventory by up to two orders of magnitude.

Light-element stable isotopes are tracers of the interactions between different volatile reservoirs and of the physical processes that shape those reservoirs. In terrestrial laboratories, carbon and oxygen isotopic studies of CO_2 released from bulk Martian meteorites have produced valuable insights into Martian geologic processes and environmental conditions.

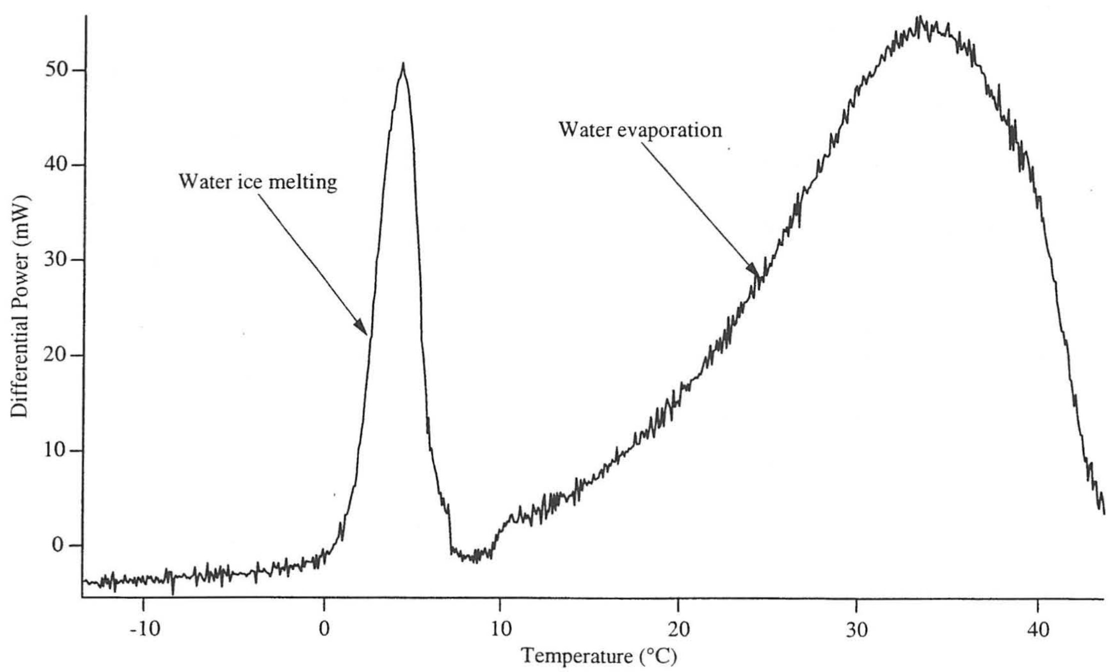
Prior studies of CO_2 released from samples heated under vacuum [e.g., *Carr et al.*, 1985; *Leshin et al.*, 1996; *Wright et al.*, 1986; *Wright et al.*, 1992] suggest the presence of three main carbon-bearing components distinguished by their temperature of release and their isotopic composition. The three components are a low-temperature component, which probably represents terrestrial contamination, a middle-temperature component, produced by the breakdown of Martian carbonate, and a high-temperature component, representing either the release of Martian magmatic volatiles, or further terrestrial contamination. The carbonate component is interesting because its $^{13}C/^{12}C$ ration varies by ~4% from meteorite to meteorite. This variation probably reflects differences in the source of fluids from which the carbonates formed (e.g., the fraction of meteoric versus magmatic components in these fluids) or the variation of isotopic composition of the meteoric component with time due to variations in atmospheric isotopic composition.

Modifications for future opportunities: Even though TEGA is well suited for study of these important scientific issues, there are a few simple modifications we would do if we were to fly the instrument again.

First, we would redesign the mounting of the lasers in the TDL spectrometer to allow better alignment to eliminate the optical fringes, which result in poor precision. For a reflight we would propose building the TDL spectrometer at U of Arizona, where we would have better control on its quality.

Second, we would add an enhancement which would permit the detection of organic compounds. This is a simple device which we were nearly able to add for Mars Polar Lander, but there was not sufficient time to add this capability. We estimate that it would have add only $250,000 to the cost of the instrument.

Fig 2. Calorimeter output of a sample with 5 mg of ice. The data show a clear peak due to ice melting and water vaporization.



SEARCH FOR ORGANIC MATTER ON MARS : COMPLEMENTARITY OF *IN SITU* ANALYSES AND LABORATORY ANALYSES OF MARTIAN SAMPLES.

A. Brack[1], A. Commeyras[2], S. Derenne[3], D. Despois[4], P. Dhamelincourt[5], M. Dobrijevic[4], C. Engrand[6], M. Geffard[7], M.F. Grenier-Loustalot[8], C. Largeau[3], J.C. Marchon[9], G. Matrajt[6], M. Maurette[6], C. Mustin[10], F. Raulin[11], F. Robert[12], C. Rodier[11], R. Sternberg[11], O. Trambouze-Vandenabeele[2], J. Trichet[13].

[1]Centre de Biophysique Moléculaire, F-45071 Orléans Cedex 2 ; [2]Univ. Montpellier II, F-34060 Montpellier Cedex ; [3]ENSCP, F-75005 Paris ; [4]Observatoire de Bordeaux, F-33270 Floirac ; [5]LASIR/Univ. Lille I, F-59655 Villeneuve d'Ascq Cedex ; [6]CSNSM, F-91405 Orsay Campus ; [7]EPHE, ENSCPB-PIOM, F-33400 Talence ; [8]Service Central d'Analyse du CNRS, F-69390 Vernaison ; [9]Lab. Chimie de Coordination, CEA, F-38054 Grenoble ; [10]CPB-CNRS, F-54501 Vandoeuvre-lès-Nancy, [11]LISA, Univ. Paris 7&12, F-94010 Créteil Cedex ; [12]MNHN, F-75005 Paris ; [13]Univ. Orléans, F-45000 Orléans.

On Earth, the molecules which participated in the emergence of life about 4 Ga ago have been erased by plate tectonics, the permanent presence of running water, unshielded solar ultraviolet radiation and by oxygen produced by life.

Since the environment of the early Mars about 3.5-4 Ga ago was probably very close to that of the early Earth, life might have emerged on Mars as well and might give us some insight into the prebiotic chemistry that took place on Earth about 4 Ga ago. Furthermore, there is a possibility that life still exists on Mars, protected from the harsh environment in some specific locales.

In order to search for life on Mars, one should look for potential biogenic markers such as organic matter and inorganic signatures (microfossils, biominerals, biogenic etching, isotopic fingerprints...) which have different degrees of resistance to the Martian environment. As biomarkers could be organic or inorganic in nature, complete organic and mineral analyses should therefore be conducted in parallel on the same sets of samples, going from the least destructive to the most destructive technique of microanalysis. Furthermore, *in situ* analyses should be complemented by high precision and high sensitivity laboratory measurements of returned Martian samples.

Due to the very oxidized Martian environment, organic molecules should be searched for in protected sites, either surface boulders or near subsurface, in layers deep enough for avoiding the oxidizing effect of the atmosphere. Molecules that should be looked for include low and high molecular weight organics (like alkanoic acids, peroxiacids, PAHs and amino acids, respectively), and macromolecular compounds like kerogens or kerogen-like materials. Previous *in situ* analyses were performed using pyrolysis systems which allow to detect organic compounds but do not always permit the identification of individual molecules. New possible analytical solutions could include gas chromatography-based techniques coupled with a mass spectrometer using multi GC columns systems, including columns able to separate enantiomers, chemical derivatization cells (using new derivatization schemes in particular for amino acid analysis), high performance liquid chromatography and supercritical fluid chromatography. Sub-systems for *in situ* molecular analysis of organics on Mars are currently developed in France.

Some of these techniques applied in the laboratory are also under development in France in order to lower the detection limit of the organic compound within the sample. This is true in particular for analyses of amino acids, with the development of new derivatizing agents associated with a variety of analytical techniques, such as capillary electrophoresis, gas chromatography, electrochromatography, high performance liquid chromatography, and a new method based on immunological reactions. Some of the detection methods used are extremely sensitive, like fluorescence (laser-induced, europium complexes), mass spectroscopy, NMR, visible and UV absorbance.

Great care should be taken in the manipulation and preparation of the samples, as contamination with terrestrial organic matter could be a problem on Earth. This requires to set up ultraclean micromanipulation facilities, and to develop critical tests to check the "virginity" of the samples analyzed in the laboratory. In that respect, the *in situ* analysis could very nicely complement analysis of return samples on Earth by giving a "zero" level of contamination (both chemical and biological), and by suppressing the problem of potential evolution of the sample during its transfer to Earth. Analytical techniques that could be used both *in situ* and in the laboratory, such as Raman confocal microscopy (or TOF-SIMS...), can provide informations on organic compounds as well as on their mineral host phase, and could help performing these tests.

A long list of other techniques applicable to the search for inorganic biomarkers on the same samples could be established, including microscopy (optical, electronic, atomic force, IR, synchrotron...) and spectroscopy (X Ray, IR, Raman, NMR, Mössbauer...), as well as mass spectrometry coupled with a variety of techniques (SIMS, nanoSIMS, TOF-SIMS, laser ablation ICP-MS...).

Cross-calibrations of the different analytical techniques (both *in situ* and laboratory techniques) at a national or international level will be required on test samples, which could be terrestrial analogs as well as extraterrestrial matter like SNC meteorites and micrometeorites.

A Reliable Earth Return System for Safe Recovery of Mars Samples. **Robert Braun[1], Brian Killough[2], Robert Mitcheltree[2], and Carol Carroll[3]**, [1]NASA Langley Research Center, Mail Stop 173A, Hampton VA 23681, **r.d.braun@larc.nasa.gov**, [2]NASA Langley Research Center, Mail Stop 173A, Hampton VA 23681, [3]NASA Ames Research Center, Mail Stop 229, Moffett Field, CA 94035.

The objective of a Mars sample return mission is to bring selected Mars surface materials to Earth. Numerous approaches for the Earth-return segment have been analyzed including propulsive or aerocapture return to low-Earth orbit followed by Space Shuttle rendezvous and direct entry. Of these approaches, ballistic entry of a small capsule terminating in a ground landing has been shown to be the lowest risk strategy. Over the past two years, significant work has been performed towards development of a robust direct entry vehicle for Mars sample return.

In June 1999, the NASA Planetary Protection Officer provided initial guidance to the former Mars Sample Return Project. The sample return phase of the mission was assigned a restricted Earth return planetary protection classification. The draft mission requirement states that the total mean probability of release of unsterilized Mars material into the Earth;s biosphere must be less than 1.0E-06 (1 in a million). This strict requirement drives the approach and design of the Earth return system.

To meet this requirement, selection of the Earth return strategy and development of the Earth return system must be guided by risk, not performance, based decisions. An initial Probabilistic Risk Assessment (PRA) was performed to address the direct entry Earth return system containment assurance reliability and to identify high-risk elements of this system. The results of this PRA identified risk elements that include thermal protection system performance during entry, spin-eject orientation and aerodynamic stability during entry, structural integrity under atmospheric deceleration and impact loads, and tracking/recovery of this system. This initial probabilistic risk quantification demonstrates that,with the proper development program, a prototypical direct entry design can satisfy the containment assurance reliability requirement.

Through the current Mars Sample Return Advanced Technology Development effort, an extensive design, analysis, and test program is presently proceeding with the aim of reducing the containment assurance risk of this system. This technology development effort, guided by a continuing PRA, focuses on key risk areas of a direct entry Earth return system including: the thermal protection system, impact dynamics, structural performance, aerodynamic stability, and ground recovery. This development program will culminate in a system validation flight test, 1-2 years prior to launch of the flight system. This flight test would include the launch, entry, and recovery of a full-scale Earth return system, as a scientific validation of the key risk elements to verify nominal design performance. The results of the initial PRA suggested several dominant failure sequences that can be validated in a flight test. These include: demonstrating the thermal protection system reliability and performance during entry, demonstrating the spin-eject orientation and aerodynamic stability during entry, demonstrating the structural integrity under atmospheric deceleration and impact loads, and demonstrating tracking and recovery of the Earth return system. This single test will directly address over 50% of the total containment assurance risk elements.

This presentation will begin by presenting the relative risk of various Earth return strategies. The results of the initial probabilistic risk assessment will be presented followed by a discussion of the development accomplishments and plans for demonstration of a highly reliable direct entry Earth return system.

Mars Exploration 2003 to 2013 – An Integrated Perspective

Geoffrey Briggs, NASA Ames Research Center
Christopher McKay, NASA Ames Research Center

The science goals for the Mars exploration program, together with the HEDS precursor environmental and technology needs, have been carefully laid out over the last several years and serve as a solid starting point for re-planning the program in an orderly way.

Most recently, the science and HEDS communities have recognized the significance of subsurface sampling as a key component in "following the water": 1. to achieve science goals related to the search for evidence of life and 2. to gain access to the most valuable resource -- water. Accessing samples from hundreds and even thousands of meters beneath the surface is a challenge that will call for technology development and for one or more demonstration missions.

Recent mission failures and concerns about the complexity of the previously planned MSR missions indicate that, before we are ready to undertake sample return and deep sampling, the Mars exploration program needs to include 1. technology development missions and 2. basic landing site assessment missions. These precursor missions should demonstrate the capability for reliable & accurate soft landing and *in situ* propellant production. The precursor missions will need to carry out close-up site observations, ground-penetrating radar mapping from orbit and conduct seismic surveys. The needs of the science and HEDS program requirements have much in common and clearly the programs should be planned as a single, continuous exploration effort.

(We note that, although we are not yet ready to carry out sample return missions, we already have the capability to make impressive gains in *in situ* exploration by deploying full-scale rovers with mobility upward of ten kilometers.)

A prudent minimum list of missions can be derived from the numerous goals and requirements; they can be sequenced in an orderly way to ensure that time is available to feed forward the results of the precursor missions.

Mars Exploration 2003 to 2013 – An Integrated Perspective: Time Sequencing the Missions

Geoffrey Briggs, NASA Ames Research Center
Christopher McKay, NASA Ames Research Center

The science goals for the Mars exploration program, together with the HEDS precursor environmental and technology needs, serve as a solid starting point for re-planning the program in an orderly way. Most recently, the community has recognized the significance of subsurface sampling as a key component in "following the water". Accessing samples from hundreds and even thousands of meters beneath the surface is a challenge that will call for technology development and for one or more demonstration missions.

Recent mission failures and concerns about the complexity of the previously planned MSR missions indicate that, before we are ready to undertake sample return and deep sampling, the Mars exploration program needs to include 1. technology development missions and 2. basic landing site assessment missions. These precursor missions should demonstrate the capability for reliable & accurate soft landing and *in situ* propellant production. The precursor missions will need to carry out close-up site observations, ground-penetrating radar mapping from orbit and conduct seismic surveys. Clearly the programs should be planned as a single, continuous exploration effort.

A prudent minimum list of missions, including surface rovers with ranges of more than 10 km, can be derived from the numerous goals and requirements; they can be sequenced in an orderly way to ensure that time is available to feed forward the results of the precursor missions. One such sequence of missions is proposed for the decade beginning in 2003.

ELEMENTAL, ISOTOPIC, AND ORGANIC ANALYSIS ON MARS WITH LASER TOF-MS.

W. B. Brinckerhoff and T. J. Cornish, The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel MD 20723-6099 (William.Brinckerhoff@jhuapl.edu).

Introduction: The in-depth landed exploration of Mars will require increasingly sophisticated robotic analytical tools for both *in situ* composition science [1] and reconnaissance for sample return [2]. Beyond dust, rock surfaces, and topsoil, samples must be accessed within rocks and ice, well below surface soil, and possibly in elevated deposit layers. A range of spatial scales will be studied, and for the most information-rich microscopic analyses, samples must be acquired, prepared, and positioned with high precision. In some cases samples must also be brought into a vacuum chamber. After expending such resources, it will be important to apply techniques that provide a wide range of information about the samples. Microscopy, mineralogy, and molecular/organic, elemental, and isotopic analyses are all needed, at a minimum, to begin to address the *in situ* goals at Mars. These techniques must work as an efficient suite to provide layers of data, each layer helping to determine if further analysis on a given sample is desired.

In the spirit of broad-band and efficient data collection, we are developing miniature laser time-of-flight mass spectrometers (TOF-MS) for elemental, isotopic, and molecular/organic microanalysis of unprepared solid samples. Laser TOF-MS uses a pulsed laser to volatilize and ionize material from a small region on the sample. The laser energy and focus can be adjusted for atomic and molecular content, sampling area, and depth. Ions travel through the instrument and are detected at a sequence of times proportional to the square root of their mass-to-charge ratios. Thus, each laser pulse produces a complete mass spectrum (in less than 50 μs). These instruments can now be significantly miniaturized (potentially to the size of a soda can) without a loss in performance. This effort is reviewed here with an emphasis on applications to Mars exploration.

Laser TOF-MS Instruments: Prototypes at APL include the following features pertinent to *in situ* analysis on Mars:

1. The laser spot diameter is adjustable between 10 μm and 500 μm, covering a range of mineral grains.
2. Sample preparation is not required.
3. A micro-imager with a few-mm FOV permits the preselection of the laser analysis position.
4. Repeated laser pulses permit analysis of material in and below dust/weathering layers (up to 10's of μm).
5. TOF-MS has an unbounded mass range: elements through large organic molecules (10^2 - 10^5 amu) are detected.
6. Detection limits are ~ 0.1-10 ppm for most elements.
7. Resolution of $m/\Delta m > 1000$ (FWHM) is achieved.
8. Precision of rock-forming element abundance ratios, such as Mg:Si, Al:Si, Mg*, (Na+K):Si, Fe:Si, and Fe:Mn, is sufficient to distinguish general classes.
9. Isotope ratios are < 3% RSD for many elements.
10. Element detection in grains helps identify mineral types and markers for further organic analysis.
11. The initial few spectra instantly give a survey of major and minor species over the entire mass range.
12. Sequences of spectra provide surface and depth profiles, trace elements and organics, and improve quantitation.
13. Mass (< 2 kg) and power (2 - 5 W) are low enough for multiple deployment platforms, including rovers.

Laser Ablation TOF-MS: Work with a laser ablation mass spectrometer (LAMS) [3,4] has shown that elemental and isotopic analysis of rocks and powders can be obtained with a Nd:YAG laser focused to 10^9 W cm^{-2}, in a TOF-MS less than 20 cm in length. Such high irradiance produces a large flux of prompt atomic ions (and essentially no molecules). Ion pre-acceleration was not used; the kinetic energies (up to 250 eV) were focused and windowed. Precision of Mg, Al, S, Ca, and Fe ratios to Si permitted differentiation between chondrite classes [4]. Figure 1 shows a *single-shot* LAMS spectrum of the simulant soil JSC Mars-1 [5]. Accumulated data were in agreement with bulk abundances inferred from oxide analysis. In addition, categories of low and high (Ca+Ti):Si ratios could be distinguished in sequences of spectra, consistent with XRD data identifying two particle types, one of which is dominated by Ca-feldspar and Ti-magnetite [5].

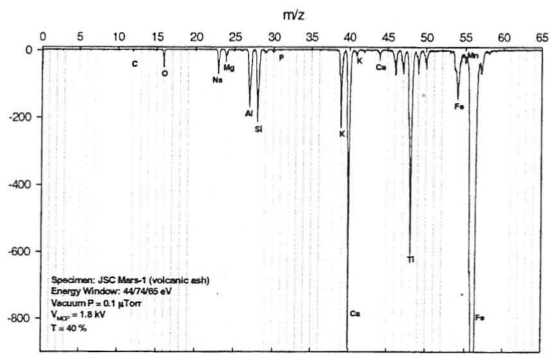


Figure 1 Single-shot LAMS spectrum of JSC Mars-1.

Laser Desorption TOF-MS: While laser ablation is particularly useful for bulk and microprobe elemental analysis with minimal fractionation, and for depth profiling, the lower-irradiance regime termed *laser desorption* is more appropriate for organic/molecular analysis and some isotope and trace element studies. Designing a single, miniature instrument to cover both ablation and desorption TOF-MS would normally be extremely challenging due to ion optical demands. However, using a simple, coaxial geometry and novel ion extraction and curved-field reflectron designs, we have developed [6] a laser TOF-MS (Figure 2) that increases the sensitivity, resolution, and mass range, compared to LAMS, while actually reducing the size. The following features are key for Mars:

Curved-Field Reflectron Laser ablation produces ions with energies up to hundreds of eV. A two-stage reflectron, such as used in LAMS, focuses only about 20% of this range in each laser shot. The full distribution may be sampled by scanning the reflectron, but the number of laser shots may be limited by the power budget and the need to interrogate individual mineral grains. We are using a novel curved-field reflectron [7] that provides nearly ideal focusing over a much higher fraction (up to 90%) of ion energies. This reflectron thus realizes both: (a) eliminating scanning of ablation energies for elemental analysis; and (b) capturing all the post-source decay products of large organic molecules, which are vital for identifying those species.

LASER TOF-MS FOR MARS: W. B. Brinckerhoff, T. J. Cornish, and A. F. Cheng

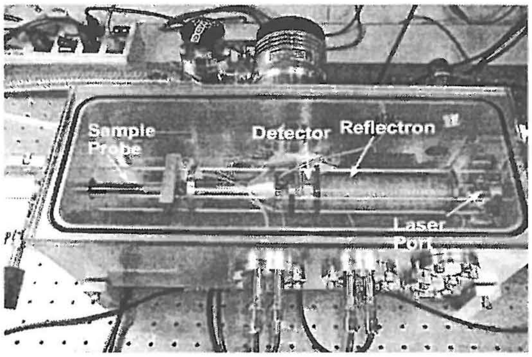


Figure 2 Laser TOF-MS prototype in a test chamber.

High Transmission Efficiency To measure small abundance fluctuations and detect trace (sub-ppm) species, we must maximize the fraction of ions that reach the detector. The ion transmission in LAMS [3], approximately 10^{-6} - 10^{-5}, was due to the inlet aperture stop (10^{-3}), energy windowing (10^{-2} - 10^{-1}), and the cumulative grid transparency (10^{-1}). The new reflectron design eliminates much of the latter two limitations. To maximize transmission through the inlet (a center hole in the detector assembly), we are using a novel gridless source that accelerates and collimates ions leaving an unprepared sample surface. The ion source efficiently transfers nearly all ions into the reflectron, giving a critical sensitivity boost in the desorption range.

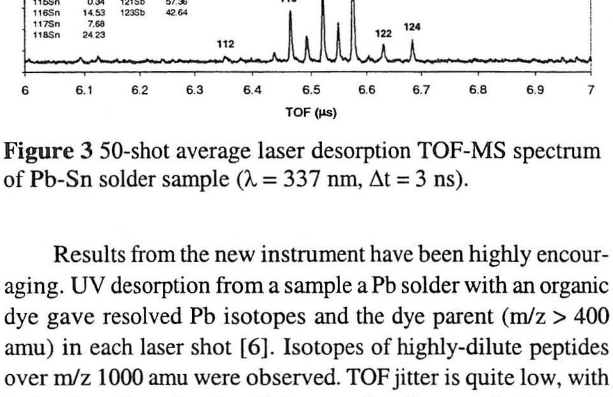


Figure 3 50-shot average laser desorption TOF-MS spectrum of Pb-Sn solder sample ($\lambda = 337$ nm, $\Delta t = 3$ ns).

Results from the new instrument have been highly encouraging. UV desorption from a sample a Pb solder with an organic dye gave resolved Pb isotopes and the dye parent (m/z > 400 amu) in each laser shot [6]. Isotopes of highly-dilute peptides over m/z 1000 amu were observed. TOF jitter is quite low, with both minor-Sn and major-Pb isotopes baseline-resolved after 50 shots (Figure 3). We are currently determining detection limits for various organic species in a range of soils and meteorites.

Enabling Technology Developments: To realize the great analytical potential of laser TOF-MS on Mars, the instrument must be further miniaturized and ruggedized. This necessity extends also to laser, sample handling, and vacuum systems.

Next-Step TOF-M S We have already begun to develop a further miniaturized instrument (Figure 4) that goes a long way toward a package that can be qualified for Mars. The design incorporates *in vacuo* voltage control and an essentially monolithic reflectron made from flexible circuit board.

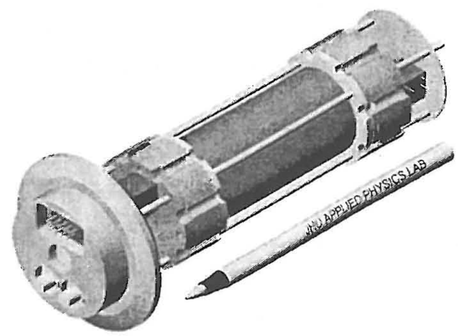


Figure 4 Highly-miniature TOF-MS (140 mm pen).

Enabling Accessories Recent years have witnessed significant strides in miniature laser and vacuum pump technologies. It is now possible to obtain very small and rugged Q-switched diode-pumped Nd:YAG UV lasers, with sufficient power for TOF-MS, from commercial sources. Long-lifetime, low-power throughput pumps, required on Mars, are slowly emerging. For example, we are working with Creare, Inc. to develop a miniature turbomolecular drag pump (< 100 mm) that can exhaust directly to Mars ambient (< 10 Torr). A mated vacuum sample insertion mechanism is also under development.

Finally, we a working to define a combined laser-desorption and evolved-gas source for TOF-MS to provide complete coverage of refractory and volatile species in Mars surface materials with a single, highly-sensitive analyzer.

Acknowledgments: The authors wish to thank R. W. McEntire, A. F. Cheng, G. G. Managadze, S. A. Ecelberger, P. Mahaffy, and R. C. Benson. Supported was provided in part by NASA PIDDP Grant #NAG5-4548 and by NASA/APL Advanced Technology Development contract #NAS5-97271.

References:

[1] Meyer C., Treiman A. H., and Kostiuk T., eds. (1996) *Planetary Surface Instruments Workshop*. LPI Tech. Rpt. 95-05, Lunar and Planetary Institute, Houston. 115 pp. [2] Gulick V. C., ed. (1997) *Mars 2005 Sample Return Workshop*. LPI Tech. Rpt. 97-01, Lunar and Planetary Institute, Houston. 91 pp. [3] Brinckerhoff W. B. et al. (2000a) *Rev. Sci. Instrum., 71*, 536; Brinckerhoff W. B. et al. (1999) *LPS XXX* 1752-1753. [4] Brinckerhoff W. B. et al. (1998a) *LPS XXIX* 1789-1790; Brinckerhoff W. B. et al. (1998b) *Third IAA Conference on Low-Cost Planetary Missions*, #IAA-L98-1106, International Academy of Astronautics, Pasadena. [5] Allen, C. C. et al. (1998) *EOS, 79*, 405. [6] Brinckerhoff W. B. et al. (2000b) *LPS XXXI* 1817-1818; Brinckerhoff W. B. et al. (2000c) *Fourth IAA Conference on Low-Cost Planetary Missions*, #IAA-L00-1008, International Academy of Astronautics, Laurel. [7] T. J. Cornish and R. J. Cotter, Nonlinear field reflectron. United States Patent #5,484,985 (The Johns Hopkins University, November 7, 1995).

THE MARS FRISBEE: A SMALL, LIGHTWEIGHT DEPLOYMENT MECHANISM FOR IN-SITU INSTRUMENTS ON THE PROPOSED MARS SCOUT LANDER. D. T. Britt, Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996, dbritt@utk.edu. .

Introduction: The proposed Mars Scout lander is conceived as a robust airbag landing system to deliver small five-kilogram scientific payloads to a variety of Martian terrains. This lander has very strong constraints on delivered instruments in mass, volume, and footprint. Another constraint on possible instruments will be the large footprint of the airbag landing system that will surround the lander after it deflates. This could make difficult to deploy in-situ instruments such as Alpha X-Ray Proton or Mossbauer spectrometers without a relatively large and heavy deployment arm.

The Mars Frisbee: A way around the problem of deploying in-situ instruments is to encase them in a small, lightweight probe that resembles a "Frisbee. This Frisbee would have a flat and symmetrical geometry that has only two stable orientations on the surface. The probe instrument (for example either a APXS or a Mossbauer spectrometer) would be double-sided with two opposing viewing windows and corresponding sets of detectors, ensuring that whichever side comes to rest on the surface, the instrument will be able to view the surface. This probe would be deployed by a simple spring mechanism from the lander. To save the mass of a transmitter and batteries, it would be connected to the spacecraft by a lightweight tether that would serve for both power and communications. Another option would be an independent probe with modest battery and communications capacity.

The "double sided" geometry of the instrument package would allow measurements of Martian soil early in the mission and also the Martian dust as it accumulates on the upper side of the probe. The probe can also be equipped with a single-degree-of-freedom hopping mechanism to allow for measurements at multiple surface sites. The mechanism would extend an annular disk, which surrounds the instrument viewing windows, outward from both main probe faces. Actuation is done by a single brushless DC motor, which acts on a spindle drive. The extension of the annular disk accelerates the probe away from the surface leading to a small ballistic hop to a new location. Flight azimuth cannot be predicted because it depends on the probe's tilt on the surface at its first location, but any additional in-situ measurements of an unknown area would be of significant scientific benefit. Since the annular disks are simultaneously deployed on both main faces of the probe, hopping is ensured regardless of initial surface orientation. With a 5-meter lightweight tether providing power and communications, the probe and instrument package would have a mass of approximately 1.5 kg. The surface measurements that instruments like Alpha X-Ray Proton or Mossbauer spectrometers could provide would greatly extend our knowledge of the surface of Mars and enhance the scientific robustness of the Scout landing system.

. A Small, Lightweight Deployment Mechanism for in-situ Instruments on the Proposed Mars Scout Lander

Mars Stratigraphy Mission. C. J. Budney[1], S. L. Miller[1], and J. A. Cutts[1], [1]Jet Propulsion Laboratory, Pasadena, CA 91109-8099, Charles.J.Budney@jpl.nasa.gov, Sylvia.L.Miller@jpl.nasa.gov, James.A.Cutts@jpl.nasa.gov.

Introduction: The Mars Stratigraphy Mission lands a rover on the surface of Mars which descends down a cliff in Valles Marineris to study the stratigraphy. The rover carries a unique complement of instruments to analyze and age-date materials encountered during descent past 2 km of strata.

Science Objectives: The science objective for the Mars Stratigraphy Mission is to identify the geologic history of the layered deposits in the Valles Marineris region of Mars. This includes constraining the time interval for formation of these deposits by measuring the ages of various layers and determining the origin of the deposits (volcanic or sedimentary) by measuring their composition and imaging their morphology.

Science and Measurement Requirements: Specific science requirements for the mission include:

1. Examine a cliff or ridge containing at least 2 km of exposed layering.
2. Determine the mineralogy and chemistry of layers at 1-m intervals down the stratigraphic column.
3. Determine the mineralogy and age of core samples collected from layers at 100-m intervals down the stratigraphic column.
4. Determine morphology of layers continuously along the stratigraphic column.
5. Provide context for layers continuously along the stratigraphic column.

Measurement requirements include the following:

1. Composition of the layers (mineralogy and chemistry). This can be accomplished using Raman and X-ray fluorescence (XRF) spectrometers.
2. Age dating with an accuracy to ±100 My or better. Age dating starts at the top of stratigraphic column. This will allow comparison with age estimates derived from cratering statistics.
3. Multispectral imagery.

Operational requirements include the following:

1. Rover requirements.
   i) Rover must find cliff edge or ridge.
   ii) Rover must be able to be lowered over cliff edge. The mobility system must handle slopes from horizontal to vertical.
   iii) Rover must stop every 1-m interval for science measurements.
2. Ground interactions: At the dating site, images of the local scene will be acquired and downlinked to the science team. This and other data will allow the science team to select locations for collecting samples for analysis. The sample will be obtained through drilling to 5 cm.

Mission Design: The mission as designed would launch in 2007 on a Delta 7925. The mission would arrive at Mars in 2009 using a Type IV transfer. At arrival the lander would enter Mars's atmosphere directly and use active lift-vector roll control to land in a circle with 20 km diameter centered at about 14° S and 68° W, near the southern canyon wall of Valles Marineris. A soft landing would be achieved by using a parachute followed by terminal descent on liquid-fuelled rocket motors. After landing, the rover would deploy and begin a maximum 50-day traverse to the canyon clifftop. At the clifftop, the rover would anchor a tether which it would use to rappel 2 km or more down the cliff to perform a 200-day study of the strata exposed in the cliff. During the traverse and the cliffside science operations, the rover would communicate with Earth via a communications orbiter in a low equatorial orbit.

Flight System: The flight system has four principal elements: the cruise stage, the entry/descent system (heatshield, backshell, and parachute), the lander, and the rover. The rover is considered to be the payload of the lander. The lander carries no other instruments and has no power or communications capability.

The architecture for the Mars Stratigraphy mission is similar to that of the former MSP 2001 mission. A cruise stage delivers the entry system to the Mars atmosphere. The carrier is discarded prior to atmospheric entry and an actively controlled ballistic entry is used to provide precision targeting capability to the desired landing site. The entry system (heatshield, backshell, and parachute) is discarded after atmospheric entry and the lander provides powered descent. A relatively soft landing will be made at an altitude of up to 4.5 km near the desired touchdown site. Laser radar will be used for determining altitude and 3D imaging of the local terrain to provide for obstacle avoidance during final approach.

The rover is deployed from the lander and proceeds to the cliff edge. The rover anchors a cable near the cliff edge and lowers itself down the cliff side, collecting data as it descends. The rover is similar in capabilities to the Athena rover, but with an inflatable wheel mobility system. The mobility system will handle slopes from horizontal to vertical, including the slopes in between. The rover also includes a cable and anchoring system for lowering the rover down a cliff.

Launch margin was sufficient to allow examination of the option of delivering two rovers on a single lander.

Technology: The Mars Stratigraphy Mission was designed assuming spacecraft technologies that are planned for 2004. The rover mobility and cable system, the age dating instrument and the XRF are additional required technology developments.

Study history and acknowledgements: This study was conducted August 1999 by the JPL Advanced Projects Design Team (Team X). Much of this abstract is extracted from the Team X report.

Conclusions: The Mars Stratigraphy Mission is an exciting and feasible concept for exploration of the stratigraphy of Mars.

MARS SCOUT: MICROMISSIONS TO INVESTIGATE MARTIAN ENVIRONMENTS. Nathalie A. Cabrol[1], Gian Gabriele Ori[2], Edmond. A. Grin[1], Michael H. Sims[3,] Lucia Marinangeli[2], Christopher McKay[1], John Marshall[3], Hans Thomas[3], Maura Rabbette[1], Ragnhild Landheim[1]. [1]NASA Ames Research Center, Space Science Division, MS 245-3, Moffett Field, CA 94035-1000. [2] International Research School of Planetary Sciences (IRSPS), Pescara, Italy, [3]NASA-ARC/ARA, [4]NASAARC/ARA.Email:ncabrol@mail.arc.nasa

Rationale

Environments can be local, regional, or global. They can include one or more geological, morphological, climatological, and biological types. An environment also represents all the interactions that take place in the identified boundaries. Current planned missions to Mars in the Surveyor Program assume a good knowledge of the Martian environment that we do not have because it cannot be obtained only from orbit. There is a missing step between orbital data and the complex Surveyor missions to be landed that needs to be filled. The Ames/IRSPS Scout Mission Concept originally proposed in February 1999 filled this gap by landing a series of small (less than 10 kgs. each) scout missions.

1. Overall Goal and Objectives

The Mars Environment Scout Mission Concept is being developed to explore the possibility of sending a series of small, simple, and inexpensive stations to the surface of Mars. The objective(s) would be to document either: (a) the environmental diversity of Mars, (b) a specific Martian environment, and/or (c) a region of interest. This type of missions will provide critical information about environments that is currently not available, and could also be used as precursors helping the design, preparation, and planning of more complex future missions to come.

2. Background:

For the past 30 years, the missions that have landed on Mars have documented the Northern Plains only, first with the Viking I and II missions in Chryse and Utopia Planitiae, and recently in the Ares Vallis floodplain during the Pathfinder mission. These missions have provided information about one type of Martian environment only, leaving 99% of the planet unexplored. The coming Surveyor missions in 2001 and 2003 are aiming South in the Cratered Uplands, from which we have only limited knowledge from Viking and MGS orbital imagery. These missions are self-limited in engineering and science potential since they are planned in the rigid framework of existing (and not necessarily adapted) lander/rover technology design and science theories constructed from orbital data. The likely outcome is thus to send complex (and potentially non-adapted) missions to unknown environments, with a higher risk of engineering failure or science payload inadequacy. The Mars Environment Scout Mission Concept proposes to fill the gap between orbital data and complex science mission landings by providing "eyes" on Mars that will transmit the necessary data to design adapted and cost-effective complex missions, and that can be used also as "missions on their own" to document specific scientific questions (e.g. where to collect the samples for return) -- outside, or as a complement, to the Surveyor Program -- in a cost-effective fashion.

3. Simple and Cheap Onboard Science Payload with Maximum Science Return

While tens of thousands of orbital images of Mars have been archived, only three panoramas of Mars currently exist, all located in the Northern Plains. Considering the diagnostic importance of ground imagery in science and engineering, the urgency is to obtain quickly more images from the ground. The priority of scout missions will be to land imaging systems that will acquire high-resolution images associated with spectral capabilities. In the absence of mobility, the potential of such simple mission could be widely broadened with the addition of a small onboard balloon carrying a camera that could provide high-resolution images of the landing regions beyond the spatial limitation of the station high-resolution imager (see Sims, et al. these proceedings).

Science Payload: The science payload contents have to be determined but they need to strongly emphasize key-elements such as imagery and mineralogy. They should be of a mass that allows each scout mission to include a cluster of 10 to 15 stations. The number of stations must include a margin for potential failure of 1 or 2 stations without decreasing the effectiveness of the mission. Moreover, considering the number of stations, it is also suggested that 1 or 2 stations out of the 10-15 should be sent in places that are not accessible to a rover and/or lander (e.g. *chaotic terrain, fretted terrain, volcanic caldera, fault systems, dune fields, ridged terrain*). In case of successful deployment of these stations in "high-risk terrain" the science outcome and acquired knowledge will be tremendous. In case of failure, it does not jeopardize the rest of the scout mission.

Communication: Such simple missions could be ready to fly in the year 2004 or 2005. At this time, Mars Express will be in orbit, perhaps also the 2001 and 2003 orbiters. In addition, ASI is considering the deployment of a network of communication satellites in orbit around Mars in the same period. These orbiters could relay the data from the stations (and possibly small balloons). Details of data rate, communication windows have to be evaluated.

4. Possible Concepts of Scout Missions

In the following section, the term "cluster" defines a series of landed stations that are not communicating with each other. The stations are independent and some degree of failure does not jeopardize the entire mission.

Planetwide Cluster I: The goal is to document the Mars environmental diversity and obtain as much information as possible from as many diverse environments as possible (e.g. volcanic, aeolian, polar, aqueous, glacial regions). The engineering constraints are limited since the stations are landed randomly at the surface of Mars (no precision landing). The chances of reaching different environmental types is both a function of the number of probes, and the representativity of these environments at the surface of Mars.

Planetwide Cluster II: The goal is to document the diverse aspects of one Martian environment, for instance water and aqueous environments. The scout mission probes will target, for example, lakes, outflows, sapping valleys, deltas, and hydrothermal springs. Other thematic missions could visit: (a) volcanic regions of Mars and target volcanic structures of different types, diverse lava flows, etc, (b) aeolian formations, or (c) glacial environments. This strategy requires precision landing. It could be a powerful method of preparing more complex missions in those domains, especially focused on the search for life.

Regional Cluster: The area covered by the scout mission probes could be hundreds to thousands of square kilometers of a region of high-scientific interest. This strategy could be used as a precursor to a more complex mission. This preliminary mission could be of high value, for instance, to assess the conditions at the site of a future Surveyor mission. It could also be used to understand the past activity of a region as a whole system (e.g., a valley debouching in a lake), the various aspects of the most important geological stratigraphical stages (e.g. Noachian, Hesperian, Amazonian).

The objectives that can be reached by the Mars Environment Scout Mission Concept will provide critical information that are of interest for the *Surveyor Program*, the *Astrobiology Institute*, and the *Human Exploration Program*.

MAGNETIC FIELD OF MARS. J. C. Cain, B. Ferguson, D. Mozzoni, *Florida State University, USA, (cain@geomag.gfdi.fsu.edu)*, L. Hood, *Lunar & Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, (lon@lpl.arizona.edu.*

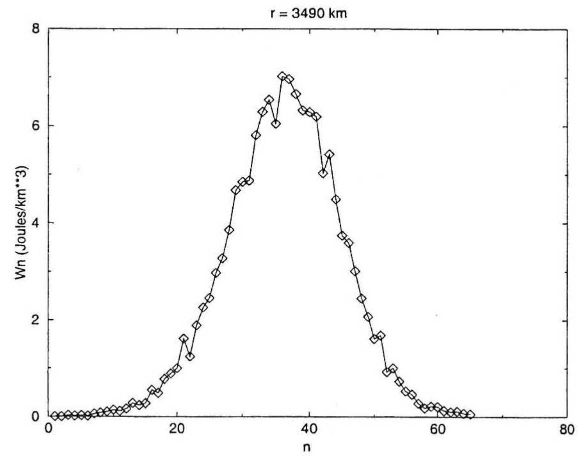


Figure 1: Energy density for each degree N evaluated at $r = 3490km$

An internal potential function was created using the averaged MGS vector data released by Mario Acuña for altitudes from 95 to 209 km above the Martian geoid, all longitudes, and latitudes from 87 degrees south to 78 degrees north. Even with some gaps in coverage it is found that a consistent internal potential function can be derived up to spherical harmonic terms of $n = 65$ using all three components of the data. Weighting the data according to the standard errors given, the model fits to 7–8 nT rms. The energy density spectrum of the harmonics is seen to peak near $n = 39$ with a value of 7 J/km^3 and fall off to less than 0.5 J/km^3 below $n = 15$ and above $n = 55$. Contour maps of the X (north) component drawn for 100 km altitude show the strongly anomalous region centered at 60 degrees S latitude and 180 degrees longitude, as well as the alternating east–west trends already observed by other groups. Maps of the other components show the anomalous region, but not the east–west trends. The dichotomy is also maintained with much weaker anomalies bounding the northern plains.

The results herein as as well as those of others is limited by the sparse low–altitude data coverage as well as the accuracy of the observations in the face of significant spacecraft fields. Work by Connerney and Acuña have mitigated these sources somewhat, but the design of the spacecraft did not lend itself to accurate observations.

Recent results reported by David Mitchell of the ER group have shown that the field observations are significantly influenced by the solar wind with the possibility that the present results may only reflect that portion of the internal field visible above 95 km altitude. Depending on the solar wind, the anomaly field may be shielded or distorted to produce spurious results. The spectrum we have obtained so far may only see the stronger portion of the signal with a significant weaker component hidden.

Measurements of crustal anomalies versus relative ages of source bodies combined with later absolute dating of Martian geologic units could lead to a quantitative constraint on the thermal history of the planet, i.e. the time when convective dynamo generation ceased in the core.

Determination of directions of magnetization of anomaly sources as a function of age combined with the expectation that the Martian dynamo field was roughly aligned with the rotation axis would lead to a means of investigating polar wandering for Mars. Preliminary analysis of two magnetic anomalies in the northern polar region has yielded paleomagnetic pole positions near 50 N, 135 W, about 30 degrees north of Olympus Mons. This location is roughly consistent with the orientation of the planet expected theoretically prior to the formation of the Tharsis region.

In the future, more accurate observations of the vector field at the lowest possible altitudes would significantly improve our understanding of Martian thermal history, polar wandering, and upper crustal evolution. Mapping potential resources (e.g., iron-rich source bodies) for future practical use would also be a side benefit.

MARS SCIENCE WITH SMALL AIRCRAFT.
W. M. Calvin[1], C. Miralles[2], B. C. Clark[3], and G. R. Wilson[4]. [1]*University of Nevada-Reno*, Geological Sciences MS 172, Reno, NV 89557, wcalvin@unr.edu; [2]*AeroVironment, Inc.*, Simi Valley, CA, miralles@aerovironment.com; [3]*Lockheed-Martin Aerospace*, Littleton, CO, benton.c.clark@lmco.com; [4]*Jet Propulsion Laboratory*, Pasadena, CA, Gregory.R.Wilson@jpl.nasa.gov.

Background

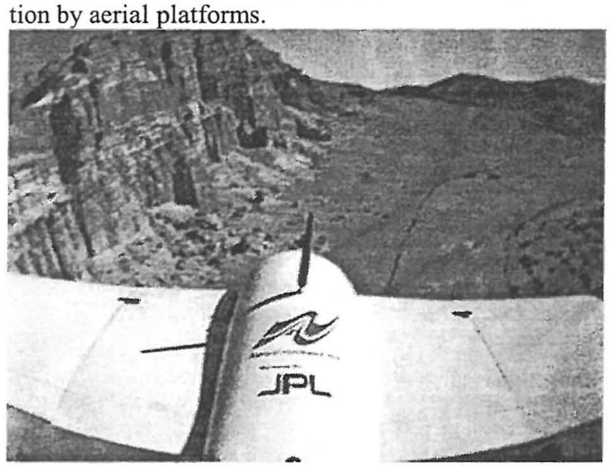
The Mars program has articulated a strategy to answer the question "Could Life have arisen on Mars?" by pursuing an in depth understanding of the location, persistence and expression of water in the surface and sub-surface environments. In addition to the need to understand the role of water in climate and climate history, detailed understanding of the surface and interior of the planet is required as well. Return of samples from the Martian surface is expected to provide key answers and site selection to maximize the science gleaned from samples becomes critical.

Current and past orbital platforms have revealed a surface and planetary history of surprising complexity. While these remote views significantly advance our understanding of the planet it is clear that detailed regional surveys can both answer specific open questions as well as provide initial reconnaissance for subsequent landed operations. **Aerial platforms offer the unique capability to bridge the gap in both resolution and geographic coverage between orbit and surface operations.**

Value and Application of Small Aircraft

- Detailed Local/Regional Survey
- Access Rugged/Hazardous Terrain
- Traverse scales greater than rovers
- Provide Lateral Context
- Better Resolution than from orbit
- Targetted Navigation and Control
- Controlled Descent Imaging
- In-situ Atmospheric Measurement

A number of exciting and interesting results from the instruments on the Mars Global Surveyor Spacecraft have demonstrated that the surface of Mars is layered everywhere[1]. These layers are well resolved in MOC images and yet they are below the resolution of any current or planned spectral instrument which would provide information on their composition. This is especially true of the layers exposed in the Valles Marineris and in the Polar layered terrains. Areas that express mineralogic or magnetic diversity [2,3] are also exposed in regions at spatial scales of one to a few hundred kilometers. Detailed understanding of the unique areas is desirable yet these lateral distances are beyond the scope of rovers and are ideal for exploration by aerial platforms.



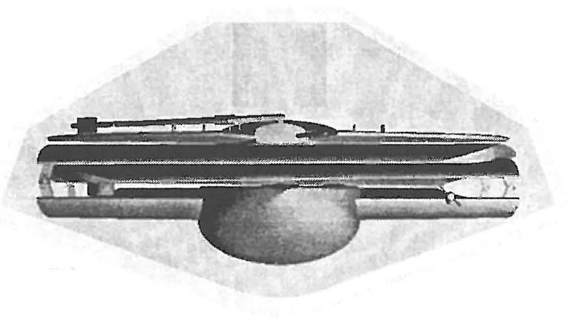
With regard to landing site assurance, understanding the relationship between the remotely sensed data from Viking and MGS and the meter scale aspects of the surface is crucial. Small airplanes can provide high-resolution images that can be used to determine total rock abundance and as well as the size-frequency distribution of rocks with special reference to large potentially hazardous rocks that can be compared with Viking and MGS estimates and models [4]. This link will directly strengthen the ability to accurately predict the meter scale characteristics of potential future landing sites, thereby significantly improving the probability of safe landing for the Mars Surveyor program.

Platform Description

We have pursued designs and applications for aircraft in the circa 2m-wingspan class. These include both unpowered (glider) and solid-rocket booster (boost-glider) types. Both models have simple (4-fold) aerodynamically stable layouts that can readily be accomodated in entry probes for delivery into the Martian atmosphere and subsequent deployment. The small size easily allows several to many aircraft to be launched on a single delivery spacecraft.

Flight duration in both distance and time depends strongly on total vehicle mass (including science payload and boost systems) yet the following ranges can be expected:

Science Payload:	1-3kg; 50Watts
Flight Distance:	100-300km
Flight Time:	20min to 1 hour
Altitudes:	10km to surface
Speed:	80 to 120m/sec
Flight Profile:	Gliding or Level Flight
# of Aircraft:	4 to 6 vehicles per delivery spacecraft.



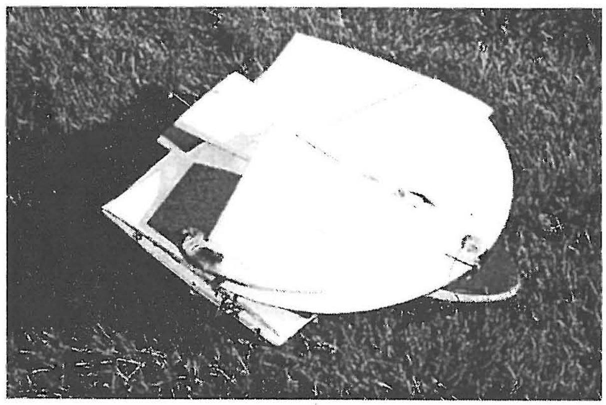
Science Payload

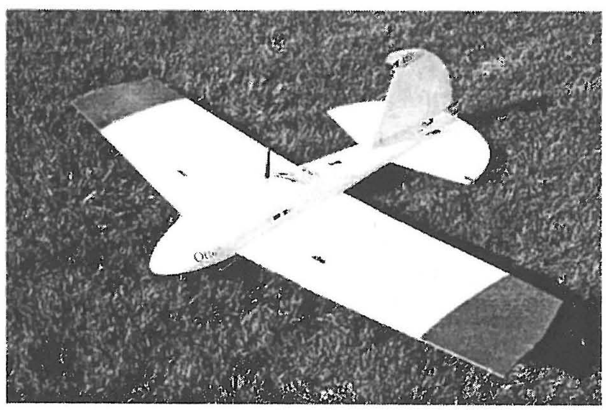
In our analysis of the application of these small aircraft it is clear that a number of small instruments exist in design or prototype that could readily be accommodated. These include the following:

Camera Systems: Wide angle, narrow angle, color or panchromatic. (0.5kg)
Spectrometer systems: VIS/NIR/SWIR. Pushbroom or point technologies. (1kg)
Dust/Cloud Sensors: Dust opacity, nephelometers, grain size monitoring (electrochemical films). (0.1 to 0.5kg)
Magnetometers: Surface and subsurface fields, interference from airplane servos is not yet determined. (0.2 kg)
Atmospheric Gas Sampling: Gas chromatography/mass spectrometry (2kg)
Atmospheric Line Spectroscopy: Tunable Diode laser systems, similar to Polar Lander (1kg)
Aircraft Instruments: Return atmospheric pressure, temperature, 3-axis gyro and 2-axis accelerometer.

Technological Readiness

Significant progress toward understanding the Mars flight regime and problems of atmosperic deployment have been made in recent years. NASA Langley has qualified two wind tunnels for the conditions expected for Mars flight and conducted several airfoil and configuration investigations to validate design and experimental methods. Results from a recent 2-D airfoil test at LaRC by AV have validated design assumptions used in proposed concepts. A full scale folding model of the KittyHawk glider demonstrated successful deployment at the dynamic pressure and acceleration expected at Mars and a video will be shown at the conference. Further investigations into the transonic and low Reynolds number flight regime are being conducted under a NASA ERAST program using AVs solar powered aircraft which will fly to 100,000 feet in FY01. Many recent advances in UAV technology (miniature sensors, navigation and control algorithms, folding wings) are also directly applicable.





References: [1] Malin et al., Science, v. 279, p. 1681, 1998. [2] Christensen et al., JGR, 2000. [3] Connerney et al., Science, v. 284, p. 794, 1999. [4] Golombek and Rapp, JGR, v. 102, p. 4117, 1997.

ORBITAL SAR AND GROUND-PENETRATING RADAR FOR MARS: COMPLEMENTARY TOOLS IN THE SEARCH FOR WATER. B. A. Campbell[1], J.A. Grant[2], [1]Center for Earth and Planetary Studies, MRC 315, Smithsonian Institution, Washington, DC 20560-0315, campbell@ceps.nasm.edu; [2]SUNY College at Buffalo, Earth Sciences, 1300 Elmwood Ave., Buffalo, NY, grantja@buffalostate.edu

Introduction. The physical structure and compositional variability of the upper martian crust is poorly understood. Optical and infrared measurements probe at most the top few cm of the surface layer and indicate the presence of layered volcanics and sediments [1], but it is likely that permafrost, hydrothermal deposits, and transient liquid water pockets occur at depths of meters to kilometers within the crust [2,3]. An orbital synthetic aperture radar (SAR) can provide constraints on surface roughness, the depth of fine-grained aeolian or volcanic deposits, and the presence of strongly absorbing near-surface deposits such as carbonates. This information is crucial to the successful landing and operation of any rover designed to search for subsurface water. A rover-based ground-penetrating radar (GPR) can reveal layering in the upper crust, the presence of erosional or other subsurface horizons, depth to a permafrost layer, and direct detection of near-surface transient liquid water. We detail here the radar design parameters likely to provide the best information for Mars, based on experience with SAR and GPR in analogous terrestrial or planetary environments.

Orbital Imaging Radar. Design of an orbital SAR system for Mars must address the likely range of surface and near-surface characteristics, with the goal of a large "geologic dynamic range" for the lowest data downlink rate. The types of possible surface targets include:

a. Rough volcanic flows and surface boulder fields produced by impacts or fluvial activity.
b. Rough surfaces partially or completely mantled by fine-grained aeolian or volcanic material.
c. Lunar-like regoliths with a volume distribution of rocks suspended in a fine-grained matrix.
d. Layered sedimentary materials with possible permafrost at varying depth.
e. Surface ices in polar regions.

The goal of remotely characterizing this suite of terrains implies use of the longest possible radar wavelength, λ, for which the desired surface resolution is achievable. In general, longer wavelengths provide coarser SAR resolution for a given antenna length, and there are significant constraints on the size of potential planetary mission antennas. In addition, the backscattered signal tends to decline with wavelength as more of the signal arises from subsurface interactions. The rationale for a long wavelength is two-fold: to provide the maximum depth of penetration in layered or mantled deposits, and to avoid saturation of the backscattered signal by surface roughness at the wavelength scale. For example, it would be of little use to deploy a C-band (λ=6 cm) system at Mars, since the effective depth of penetration will be only ~1 m, and even modest surface roughness will tend to "wash out" differences among geologic units. A 70-cm signal can provide effective depths of penetration of 3-5 m, and only saturates when the surface roughness is so great as to preclude safe landing [4]. Hence, λ=20-70 cm should be pursued within the trade space of spatial resolution and signal-to-noise ratio (SNR) constraints.

The polarization of an orbital SAR is also important in determining the types of geologic interpretations that can be made from the data. For determining surface roughness, a depolarized linear (e.g., HV) echo provides the largest dynamic range with rms height, and avoids the complication of facet-like returns that contribute to polarized (HH or VV) echoes [5]. The disadvantage of depolarized returns is the lower echo relative to polarized signals, which must be factored in to the assessment of acceptable SNR. In characterizing layered or buried surfaces, a combination of HH and VV measurements is better suited to estimating the dielectric constant of the transmitting interface. While a measurement of the full scattering matrix is desirable, downlink constraints and on-board processing limits may force the selection of only one polarization mode during any given observation period. For Magellan, it was possible to obtain VV images by simply rotating the spacecraft, but there was no orthogonal antenna element to permit depolarized measurements. At Mars, the capability to measure the depolarized linear component is highly desirable, even if this requires separate imaging passes due to data rate limits.

The choice of incidence angle for SAR imaging is driven by a compromise between higher signal levels (lower angles) and improved horizontal spatial resolution (higher angles). If HH or VV data are the primary product, angles >35° are crucial to obtaining a large dynamic range between smooth and rough surfaces. At angles of 20-30° the facet-like and diffuse components of the polarized echo sum to a nearly uniform value, regardless of roughness, for rocky surfaces of similar dielectric constant. This problem is not encountered in using HV data, which provide relatively identical discrimination of roughness regardless of angle.

The overall goal of an orbital SAR for Mars is to characterize the surface and near-surface roughness, with particular emphasis on penetration of mantling layers. The ideal operating scenario for a rover searching for water is relatively smooth sedimentary terrain, with minimal aeolian mantling. In this environment, geophysical probing of the subsurface and eventual drilling are most likely to succeed. In contrast, a rover mission would be seriously compromised by a thickly mantled (i.e., optically smooth-appearing) rough surface, which would impede any type of electromagnetic, seismic, or drilling system.

Rover-Based GPR. A rover-deployable ground penetrating radar (GPR) can measure *in situ* radar properties to constrain geology and subsurface structure. Any local occurrence of liquid water will create large dielectric contrasts that are easily distinguished using a GPR. Deployment along multiple, well-positioned, short transects in the vicinity of a lander should enable mapping of radar stratigraphy and serve as a guide for direct sampling by other instruments. In recognition of this potential, a miniaturized GPR is currently in development that will target definition of radar properties to depths of 10-20 m [6]. Industry partners at Geophysical Survey Systems, Inc. (GSSI) are building the breadboard GPR; target mass, volume, and power limits are 0.5 kg, 3W, and 3400 cc, respectively. These design parameters should permit deployment on a Sojourner-class or larger Mars rover.

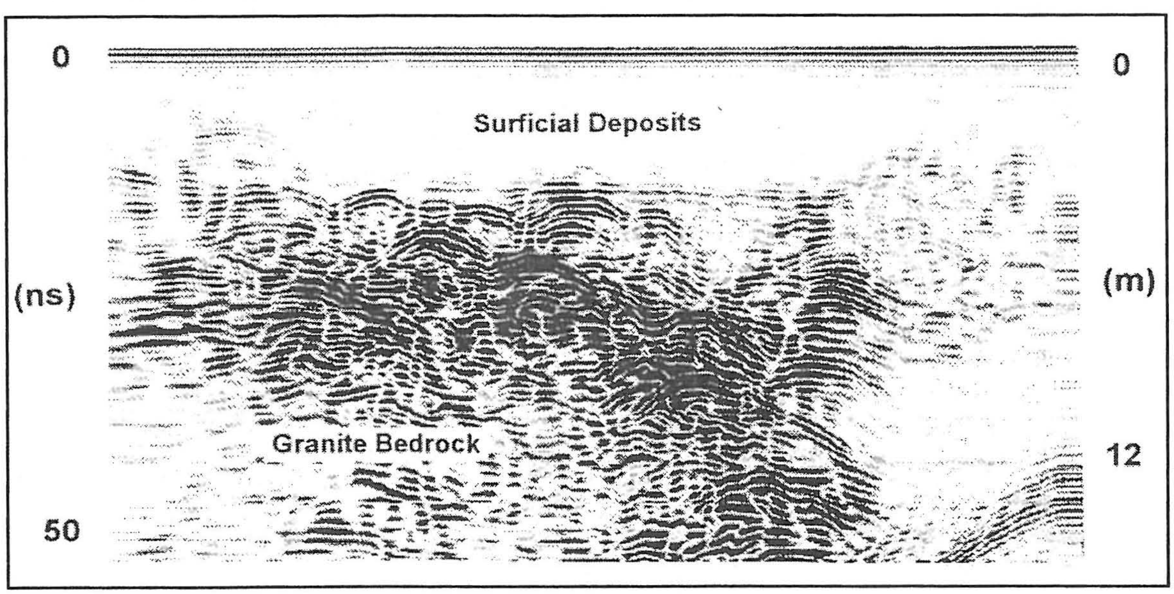
Current transducer design for Mars includes unshielded low and high frequency components whose wavelength range overlaps that of potential orbital SAR systems. The low frequency component is a monostatic "rat-tail" with a center (but easily modified) frequency of 100 MHz. The high frequency component is bi-static and operates at a center frequency of 500-600 MHz. In terrestrial settings, prototypes of these transducer components provide information on the distribution of subsurface reflectors to depths exceeding 15 m (Fig. 1). On Mars, the uppermost near-surface is expected to be dry and characterized by real dielectric constants of 3-8 and loss tangents of ~0.01 +/- 0.005 [7]. Under these conditions, a GPR with an operating delay interval of up to 1 μs should readily penetrate to depths of 10-20 m.

Strawman Radar Mission. We propose a mission that combines SAR and GPR systems to search for near-surface water on Mars. The rover-deployed GPR would be carried on the orbiter during an initial radar mapping phase. During this period, the SAR would focus on areas of high interest identified in previous remote sensing observations. Radar backscatter data would be analyzed to narrow the search to regions with roughness suitable for safe landing and a high probability of successful *in situ* probing. After this initial phase, the rover would land at the chosen site and conduct a series of traverses to map the near-surface layering, permafrost, and identify possible water pockets. If mass and power constraints permit, drilling for samples from interesting layers might also be attempted.

Work supported by NASA PIDDP Grant NAG5-4569.

References. [1] Malin, M.C., et al., (1998) *Science, 279*, 1681; [2] Clifford, S.M. (1993) *JGR, 98*, 10,973; [3] Carr, M.H. (1996) *Water on Mars*, Oxford Univ. Press, NY, NY; [4] Campbell, B.A., et al. (1997) *JGR, 102*, 19,307; [5] Campbell, B.A., and M.K. Shepard (1996), *JGR, 101*, 18,941-18,952; [6] Grant, J.A., et al. (2000) 31st LPSC, LPI, Houston, TX; [7] Simpson, R.A., et al. (1992) in *Mars*: 652 (Kieffer, H.H., et al., eds.), U. Arizona Press, Tucson, AZ.

Figure 1. Data collected in GSSI test-bed (sand over fractured granite bedrock) using prototype bi-static transducer. Center operating frequency is 600 MHz and data confirm the ability to penetrate to depths of ~15 m.



A REVIEW OF NEW AND DEVELOPING TECHNOLOGY TO SIGNIFICANTLY IMPROVE MARS SAMPLE-RETURN MISSIONS. F. Carsey, J. Brophy, M. Gilmore[1], D. Rodgers, and B. Wilcox, all at: California Institute of Technology Jet Propulsion Laboratory, Pasadena CA 91109 [1]Now Department of Earth and Planetary Sciences, Wesleyan University, Middleton CT 06459. (fcarsey@jpl.nasa.gov)

Introduction: A JPL development activity was initiated in FY 1999 for the purpose of examining and evaluating technologies that could materially improve future (i.e., beyond the 2005 launch) Mars sample return missions. The scope of the technology review was comprehensive and end-to-end; the goal was to improve mass, cost, risk, and scientific return. A specific objective was to assess approaches to sample return with only one Earth launch. While the objective of the study was specifically for sample-return, in-situ missions can also benefit from using many of the technologies examined.

Scientific Capabilities: Enhancement of value of sample return missions to science and future Mars activities can take several forms. For this study our examination of the key issues for Mars science provided the following science-capability objectives:

Enable Access to All Geographic Areas of Mars, Any Launch Opportunity. The current strategy is insufficient in latitude selection as the scientific goals of a mission are confined to a narrow zone of access. Future Mars missions, to engage the scientific, operational, and public communities must focus on search for water, and the study of key geological sites. The recent MOC data is revolutionizing our view of Mars, and design of future missions we cannot ignore this new information.

Enable relocation of landing site between approval and launch + several months. One clear and exiting message of MOC and MOLA is that new information can come in which is capable of utterly changing perceptions and priorities. If at all possible it is clearly beneficial to allow redirecting of landing site during the several-year period between mission approval and some time after launch. We can expect a future of orbiters with increasing capability (e.g., Mars Express), and the ability to accommodate to new data will add immeasurable vitality to the Mars program and supply additional return on investment.

Enable adaptive deployment of multiple landers. A clear enhancement of Mars exploration can be accomplished through a multiple-lander, adaptive mission strategy. Specifically, the ideal mission would include several (nominally 4-6) semi-independent, collaborative landers flown to Mars in one transporter. Each lander would have a science team and PI back on Earth. In operation, the transporter would remain in orbit around or near Mars and launch the landers in sequence. The first lander might be a long-range rover which would seek promising sample situations. The remaining landers might be simple or complex systems, all capable of returning samples back to the transporter (although a pure in-situ lander suite would be possible as well). Wen the science team for a given lander determined that a good sample or site had been located, that PI would signal the deployment of his or her lander; if appropriate, seasonal advance or weather conditions could be considered. When the landers were all expended, the MAVs returned and the samples stored, the transporter would return samples to Earth.

Technology Focus Areas Called for: The scientific support capabilities outlined above call for new approaches and technologies, but the specific technologies in question range appreciably in maturity, and this can be problematic as a system level assessment must be optimistic. For this study, technologies were examined across the NASA centers and aerospace industries, with emphasis on concepts that could mature for a 2007 opportunity. The technologies that were deemed required to these crucial enhancements to sample return were:

SEP Cruise Stage. Solar Electric Propulsion is an approach that is routinely used in some Earth satellite control systems; it has been successful in a solar system application (DS-1), and is planned for future space missions, but not, at this time, for Mars. Note that NASA has flown the one SEP engine, quite successfully. Specific to this discussion, a SEP mission could access any geographical point on Mars during desirable seasons and climatic conditions, and it would provide mass benefits in comparison to traditional cruise methods (SEP is discussed in detail in another abstract submitted to this workshop[1]). Launch from Earth is assumed to be on a commercial, chemical, vehicle.

New EDL Methods. A crucial concern is Entry, Descent and Landing, and new approaches are available, some of them include new and novel surface systems such as the inflatable rover, described below.

MiniMAV The MAV is the current baseline Mars Ascent Vehicle, and the MiniMAV is a new, simple, dramatically smaller (30 kg) vehicle concept adapted from a military design. While it has correspondingly smaller sample payload, it is seen as a step forward in collecting samples from more sites with reduced risk. There is another abstract submitted to this workshop on the MiniMAV [2].

Lander Design: Inflatables. The adaptive mission calls for a rover capable of long-range survey, where long range can mean up to a regional survey, 1000 km. The inflatable rover is an intriguing concept that is robust to hard landings, indifferent to seasons, and capable of traversing 95% of the surface of Mars. Specific mission design is needed to specify such matters as tools for navigation, collaborative tasks with other landers, instrumentation, etc. there are reasons to be reasonably optimistic concerning inflatable rover capabilities in these areas.

Other Subsurface and Rover Technologies. The NASA Cross-Enterprise Technology Development Program has generated an extensive body of new technologies. Among those useful in the context of this workshop are multiple-rover deployment strategies for a mission in which one rover might acquire a sample and load a MiniMAV bay. Other technologies that are interesting, but untested at this time, include two subsurface access instruments with Mars sample-return applications, the percussive drill for rock or ice environments and the thermal probe for the ice caps.

Multiple Landers and Various Holding Orbits. A transporter is proposed that can carry several landers in an efficient holding orbit and deploy them at PI/Science Team instructions; such a delivery system is clearly a significant new approach to planetary exploration. We will demonstrate with preliminary designs that the concept of a multiple-lander transporter in a holding orbit around or near Mars is a workable concept. Transport and deployment of six landers, of three sorts, seems currently possible.

Adaptive Mission Operations. The above strategy consists of SEP delivering to the Mars environment a multiple-lander transporter with (nominally) six landers, a mix of MAV-equipped inflatable rovers and simple MAV+grab systems, which can be dispatched to any point on the surface at a selectable schedule. In addition to completing development of these subsystem-level technologies, there is a requirement for operational procedures, monitoring methods, controls, autonomy elements, and the like. Specific mission objectives have not been specified, and a crucial issue remains the precise role of the scientists in definition and conduct of the mission.

This Presentation In our presentation we will show how the this approach enables the science and how different components interact. we will present specific system capabilities and estimates of delivered masses to the Mars surface.

Programmatic Considerations: Among the considerations to be specified in a new architecture are programmatic constraints, the details in which much that is crucial resides.

Flexibility. In the above arguments we have presented one realization of a multiple-lander approach. A significant question should be asked about the flexibility within the architecture for diversity in such areas as different landers, and, for the most part, these technical approaches are not inherently fused; they are an approach meeting the objectives of this study. In the selection of promising subsystems, the user community should look to involving itself.

Technology Status and Perception. In consideration of this concept, as well as others in this workshop, the practical issues of perception and evaluation of technical readiness are vital. In assessing this readiness one must consider the diverse communities that must concur, i.e., the scientists, the flight-mission managers, and the agency (or agencies for many missions). We note that one very significant element of our concept, SEP, is broadly established while the remainder have not reached a flight-phase design, and this is a concern; we need to select and decisively advance the technologies we will need [1]. In past "Technology Missions" were flown in an effort to allow focus on subsystem-level demonstrations without the tensions of mission level deliverables. There is nothing inherently wrong with this approach; the issue is selection of test objectives, and the scientists should claim a voice at that level.

Conclusion: In the context of putting forward a fundamentally new approach to planetary access, such as this one, our concluding message is the reminder that the users must act. The scientists must speak clearly to the long-term science objectives and consequent mission profiles, and must be closely engaged with the technology development process as that process will define what is possible in planetary exploration in the future. In effect, these actions will define NASA itself, and planetary science must lay claim to a significant role in setting the goals and priorities.

References: [1] Rodgers et al., this volume. [2] Wilcox et al., this volume.

Acknowledgement: This work supported by NASA under Contract.

THE DYNAMO ORBITER PROJECT: HIGH RESOLUTION MAPPING OF GRAVITY/MAGNETIC FIELDS AND IN SITU INVESTIGATION OF MARS ATMOSPHERIC ESCAPE. E. Chassefière, F. Forget[1], S. Smrekar[2], H. Rème, C. Mazelle, P.-L. Blelly[3], M. Acuna, J. Connerney, M. Purucker[4], R. Lin, J. Luhmann, D. Mitchell[5], M. Parrot, J.-G. Trotignon[6], J.-J. Berthelier, M. Menvielle[7], P. Touboul[8], E. Quèmerais, J.-L. Bertaux[9], J. Clarke, A. Nagy[10], J.P. Barriot, M. Blanc[11], H. Waite[12], M. Moncuquet, J.-L. Bougeret[13], G. Hulot[14], O. Grasset, C. Sotin[15], S. Bougher[16], B. Jakosky[17], D. Breuer[18], M. Parmentier[19], J. Lilensten, O. Witasse[20], [1]Laboratoire de Météorologie Dynamique (IPSL), Université Pierre et Marie Curie, 4 Place Jussieu, BP 99, 75252 Paris Cedex 05, France, tel. : (33) 1 44 27 48 19, fax : (33) 1 44 27 62 72, e-mail : eric.chassefiere @ lmd.jussieu.fr, France, [2]Jet Propulsion Laboratory, Pasadena, USA, [3]Centre d'Etude Spatiale des Rayonnements, Toulouse, France, [4]Goddard Space Flight Center, Greenbelt, USA, [5]Space Science Laboratory, Berkeley, USA, [6]Laboratoire de Physique et Chimie de l'Environnement, Orléans, France, [7]Centre d'Etude des Environnements Terrestre et Planétaires (IPSL), Paris, France, [8]Office National d'Etudes et de Recherches Aérospatiales, Paris, France, [9]Service d'Aéronomie (IPSL), Paris, France, [10]University of Michigan, Ann Arbor, USA, [11]Observatoire Midi-Pyrénées, Toulouse, France, [12]Southwest Research Institute, San Antonio, USA, [13]Département d'Etudes Spatiales (Observatoire de Paris-Meudon), Paris, France, [14]Institut de Physique du Globe, Paris, France, [15]Laboratoire de Planétologie et Géodynamique, Nantes, France, [16]University of Arizona, Tucson, USA, [17]University of Colorado, Boulder, USA, [18]Institute für Planetologie, Münster, Germany, [19]Brown University , USA, [20]Laboratoire de Planétologie de Grenoble , Grenoble, France

Introduction and general scientific context: Dynamo is a small Mars orbiter planned to be launched in 2005 or 2007, in the frame of the NASA/ CNES Mars exploration program [1, 2, 3]. It is aimed at improving gravity and magnetic field resolution, in order to better understand the magnetic, geologic and thermal history of Mars, and at characterizing current atmospheric escape, which is still poorly constrained. These objectives are achieved by using a low periapsis orbit, similar to the one used by the Mars Global Surveyor spacecraft during its aerobraking phases. The proposed periapsis altitude for Dynamo of 120-130 km, coupled with the global distribution of periapses to be obtained during one Martian year of operation, through about 5000 low passes, will produce a magnetic/ gravity field data set with approximately five times the spatial resolution of MGS. Low periapsis provides a unique opportunity to investigate the chemical and dynamical properties of the deep ionosphere, thermosphere, and the interaction between the atmosphere and the solar wind, therefore atmospheric escape, which may have played a crucial role in removing atmosphere, and water, from the planet.

There is much room for debate on the importance of current atmosphere escape processes in the evolution of the Martian atmosphere, as early "exotic" processes including hydrodynamic escape and impact erosion are traditionally invoked to explain the apparent sparse inventory of present-day volatiles. Yet, the combination of low surface gravity and the absence of a substantial internally generated magnetic field have undeniable effects on what we observe today. In addition to the current losses in the forms of Jeans and photochemical escape of neutrals, there are solar wind interaction-related erosion mechanisms because the upper atmosphere is directly exposed to the solar wind. The solar wind related loss rates, while now comparable to those of a modest comet, nonetheless occur continuously, with the intriguing possibility of important cumulative and/or enhanced effects over the several billion years of the solar system's life. If the detailed history of the Martian internal field could be traced back, and the current escape processes could be understood well enough to model the expected stronger losses under early Sun conditions, one could go a long way toward constraining this part of the mysterious history of Mars' atmosphere.

Main scientific objectives of Dynamo: Concerning atmosphere and escape processes, the main objectives of Dynamo are to :

- understand how the physical-chemical atmospheric system works, and the different stages of the atmosphere are coupled between each either, by :

→ extending chemical measurements of Mars-Express up to thermospheric/ ionospheric levels, in order to model the full atmospheric chemical system, and quantify neutral/ ion reservoirs available for escape,

→ monitoring thermospheric dynamics, and coupling with lower atmosphere,

→ characterizing ionospheric dynamics, and how dynamics couples with chemistry,

- determine, as a function of solar conditions, the nature and efficiency of the various phenomena involved in the interaction of the upper atmosphere with solar wind by :

→ characterizing the various boundaries, including the exobase, in terms of magnetic, ion, electron, energy distribution discontinuities,

→ studying fluxes of charged particles, and their space/ momentum/ energy distribution, in the ionospheric cavity and magnetotail

- study, as a function of solar conditions, the processes by which energy is transferred from the solar wind to the planetary atmosphere and how its dissipation affects its dynamics and its structure by :

→ measuring fluxes and energy distributions of entering solar wind particles, and pick up ions, in the "sputtering zone" (150-300 km) and above, as a function of altitude,

→ assessing the relative roles of solar UV absorption, electron impact, charge exchange ionization in the energy budget of the upper atmosphere and, by inference, in the global dynamics, as well as in the formation rate of pickup ions,

→ measuring upward fluxes, and energy distribution of escaping neutrals and ions, and estimating the total atmospheric loss rate, and its variations with solar wind and UV flux,

→ assessing the relative weights of sputtering, dissociative recombination and ion escape in atmospheric mass loss,

→ assessing the relative roles of sputtering and dissociative recombination in populating exospheric levels, resulting in possible positive retroaction on escape,

- analyze the role of the complex structure of the Martian magnetic field on the interaction with the solar wind,
- evaluate, through physical-chemical modelling of the whole neutral atmosphere/ ionosphere/ solar wind system, the consequences of atmospheric and ionospheric processes on the escape and long term evolution of the atmosphere.

Objectives related to the solid planet are mainly oriented toward :

- investigate at planetary scale the mantle and crust electrical conductivity,
- better define crustal magnetic anomaly sources and elastic thicknesses for small geologic features, enabling systematic process-oriented studies,
- place these sources in the stratigraphic context and understand the origin of magnetic remanence,
- evidence possible magnetic reversals, understand magnetic field history and, by inference, the thermal evolution of the planet,
- determine by gravimetry the elastic thickness (3 times better spatial resolution than MGS) and loading structure of a variety of geologic features and provinces,
- search for traces of ancient tectonism, as imprinted on magnetic high resolution maps.

Dynamo payload and planned measurements:
The nominal payload consists of : a flux gate magnetometer, a Langmuir probe, which may be used as EUV meter (under study), a energetic ion/electron spectrometer, a ion/neutral mass spectrometer, for the different types of thermal and suprathermal populations, a three-axis accelerometer, a system of density gauges, and a UV airglow spectrometer. The X-band transponder required for navigation purpose will be used for gravity measurements. The possibility of including an ultra-stable oscillator, for density profile retrieval, and plasma instruments dedicated to refined electron measurements is also studied. In the present concept, the mass of the core payload is about 10 kg, for a mean power of 15 W, and is increased up to 15 kg by adding optional instruments.

Previous instruments are used for the following purposes :

- Planetary magnetic field mapping, full coverage (improved by a factor of 5 /MGS coverage).
- Electrical structure of Mars, through measurement of magnetic variations,
- Planetary gravity field mapping, high spatial resolution (improved by a factor of 3-5/ MGS resolution).
- In situ probing of thermospheric composition, temperature and wind, full vertical/ horizontal coverage (follow up of MGS).
- In situ probing of deep ionosphere chemical/ dynamical structure : vertical, latitudinal and seasonal variations.
- In situ probing of energetic neutrals/ ions/ electrons fluxes and energy spectra in the 100-400 km altitude range (in complement of Mars-Express : z• 400 km, and Nozomi : only equatorial regions).
- In situ characterization of solar wind/ ionosphere three-dimensional magneto-hydrodynamic interaction.

References:

[1] Chassefière E., and co-authors : "The dynamo micro-orbiter project : investigation of Mars crustal magnetism and atmospheric interactions", *Mars Exploration Program and Sample Return Missions*, CNES Proceedings, O4/S10 (158), Paris, February 1999

[2] Chassefière E., F. Forget, S. Smrekar, H. Rème, C. Mazelle, M. Acuna, J. Connerney, M. Purucker, R. Lin, J. Luhmann, M. Parrot, J.-J. Berthelier, et al : The Dynamo Micro-Orbiter Project : Investigation of Mars Gravity/ Magnetic Fields and Atmospheric Interactions, *Fifth International Conference on Mars*, Pasadena, California, July 1999

[3] Chassefière, E.. The Dynamo Micro-Orbiter Project : Investigation of Mars Crustal Magnetism and Atmospheric Interactions, *AGU Spring Meeting, Supplement to EOS, April 27, 1999, S237*, 1999

DECIPHERING THE HISTORY OF MARTIAN VOLATILES : A MULTI-COMPONENT SPACE EXPLORATION PROGRAM. E. Chassefière[1], the Dynamo and Paloma teams, [1]Laboratoire de Météorologie Dynamique (IPSL), Université Pierre et Marie Curie, 4 Place Jussieu, BP 99, 75252 Paris Cedex 05, France, tel. : (33) 1 44 27 48 19, fax : (33) 1 44 27 62 72, e-mail : eric.chassefiere @ lmd.jussieu.fr.

Introduction : toward a better understanding of Mars climate evolution: To characterize Mars climate evolution requires to trace back the history of volatile species, including water. Indeed, atmospheric gases control, through UV-visible absorption and IR radiative transfer, the thermal structure of the atmosphere, the surface temperature, and ultimately the global hydrological system, which is a major component of the present Earth climate system. The composition and mass of the atmosphere is controlled by physical/·chemical processes acting as sources (outgassing) or sinks (atmospheric escape, surface weathering, physical trapping in the subsurface). The history of volatiles is influenced by inner planet processes, like core convection which may give rise to a planetary-scale magnetic field able to withhold the atmosphere from the solar wind, inhibiting escape, or mantle convection, through outgassing and recycling of gas by geochemical cycles. Conversely, atmosphere may possibly retroact on the inner planet dynamical regime, for example if large amounts of liquid water are maintained at the surface by greenhouse effect, which could favour specific tectonism styles (like plate tectonism). The history of volatiles may therefore be related, not only to climate, but also to the thermal history of the inner planet, through a complicated chain of causes and effects. It is an essential link for reconstructing the global evolution of the Mars system. Focusing on climate, it appears that, provided the present climate system is understood and modelled, it must be possible to extrapolate to the past, provided the way the atmosphere evolved is known, as well as solar emission fluxes controling thermal structure and escape.

Main scientific objectives: The primary objectives to be reached to constrain the past evolution of volatiles are :

(i) to fully understand and model the present Mars atmospheric system, including high atmospheric levels, in particular :

(ii) to characterize present ion and neutral escape mechanisms in the upper atmosphere, which directly interacts with the solar wind, in order to develop a detailed numerical modelling of important processes : photochemical escape, sputtering, ion escape ;

(iii) to measure elemental abundances, isotopic spectra of noble gases and stable isotopes in the global atmosphere, which provides a diagnostic of past escape because of induced fractionation ; the simultaneous mesurement of several elements and isotopes, in a Mars/ Earth comparative approach, should allow to identify specific escape phases and related mechanisms, and to quantify them, as well as other fractionating phenomena (due to surface interactions) ;

(iv) to trace back the past evolution of the magnetic dynamo, through both a detailed mapping of the remanent crustal magnetic field and the accurate datation of geological provinces through sample return, and the way it influenced the loss of atmospheric species by escape ;

(v) to measure isotopic ratios and abundances in mineral phases of the different materials present at the surface or in the subsurface ;

(vi) to identify, through stratigraphic measurements of dated weathered samples, secondary mineral phases, and to infer what the environmental conditions (humidity, temperature, chemical composition) were when they formed.

HOW and WHEN to reach previous objectives ?:
→ (i) Future orbiters of Mars (MARS-EXPRESS [1], NOZOMI [2], MGS-type climate orbiter), assumed to be operated in the 2003-2005 time frame, will provide, in the follow up of Viking and MGS, a complete view of the present radiative, dynamical and chemical state of low and middle atmosphere (0-80 km), and related cycles -CO_2, H_2O, dust- (MEX, future MCO), and of the equatorial ionosphere (Nozomi). MEX will also give interesting information on energetic particle fluxes, as seen from the orbit (• 400 km altitude).

There is a wide gap in the 100-300 km altitude range, where some major phenomena are taking place : formation of atomic species feeding up escape, by sputtering and/or photochemical processes, and direct removal of ionized atoms by the solar wind. Although MGS provided some information on electron fluxes and their energy distribution in this altitude range, it is necessary to perform more specific and complete measurements. The *DYNAMO* mission (*CNES/ NASA*), described elsewhere in this issue (Chassefière et al), consists of a small orbiter of Mars of low periapsis (120-130 km). It is instrumented for in situ measurements of neutral atoms and ions, thermal and suprathermal, and is planned at the present time to be launched in *2005* or *2007*.

Such an orbiter, equipped with a package including a 3-axis accelerometer and a system of density gauges, named *TERMOPAC* (*CNES/ ONERA*), described elsewhere in this issue (Berthelier et al), would provide interesting informations on thermospheric dynamics, in view to document thermospheric data bases, constructed with the help of

TGCM simulations, and refine aerobraking strategies. Flying TERMOPAC on other orbiters using aerobraking (like telecommunication orbiters) would allow to follow the Martian thermosphere along a full solar cycle.

Detailed understanding of meteorological processes, like transient eddies, planetary waves, thermal tides, requires the deployment at the surface of Mars of a network of at least 20 stations (for pressure monitoring), associated with an orbiter providing the 3-D thermal structure of the atmosphere, as well as dust opacity. This element, necessary for preparing human exploration, is of crucial importance. It is materialized by the PASCAL project (NASA/ AMES) [3]. A small orbiter, named KELVIN (CNES/ NASA) [4], equipped with a millimeter wave spectrometer, would provide temperature fields.

→ (ii) The DYNAMO orbiter is expected to provide an in-deth picture, with unprecedented altitude, latitude and season sampling, of solar wind/ atmosphere interaction and resulting escape : dissociative recombination, sputtering, ion escape. For this purpose, it is necessary to probe by in situ spectrometry deep ionospheric levels, where escaping atoms are formed, and to measure energetic particle fluxes, in order to characterize the way energetic particles originating in the solar wind interact with the neutral atmosphere.

Through a complete modelling of the Mars atmospheric system, it will be possible to extrapolate back to the past, when solar conditions were different, resulting in different escape rates.

→ (iii) In situ measurement of elemental and isotopic composition of Mars atmosphere by mass spectrometry, as done by the *PALOMA* experiment (*CNES*), to be flown on a future lander of Mars (*2005*) and described elsewhere in this issue (Jambon et al), will provide a diagnostic to test evolutive models of Mars atmosphere, constrained by orbiter measurements, under the effect of escape and other possible phenomena (surface interactions). Additionally, this experiment will provide a definitive test of the Martian origin of SNC meteorites. PALOMA will also measure radon, which is a link of the uranium desintegration chain, in order to calibrate the radiogenic helium flux at the surface, and discriminate between solar wind absorption and outgassed components of helium. Another goal, presently under study, is to measure molecular hydrogen at the ground level, which will provide constraints on thermal H and non-thermal O escape fluxes through photochemical modelling. To return atmospheric samples from Mars in a further step would be highly valuable, to confirm and refine in-situ measurements (Marty et al, this issue).

→ (iv) Flying DYNAMO, in the follow up of MGS, will provide the crustal magnetic field with high spatial resolution (• 100 km) and complete coverage, allowing to multiply by a factor of 5 the MGS coverage (about 20%). Such a resolution will allow to place magnetic sources in the stratigraphic context and understand the origin of magnetic remanence, to evidence possible magnetic reversals, therefore to decipher magnetic field history and, by inference, the thermal evolution of the planet.

→ (v) & (vi) In situ analysis, and laboratory analyses of returned samples (rocks, soils, drill cores), are the only means to reach these objectives. Note that laboratory simulations in Martian conditions of gas/ surface interaction may be of great interest to prepare and interpret future data in terms of paleoclimate records, e.g. the *EXOCAM* project (*CNES*) [5], to be fully implemented in *2003*.

References:

[1] Chicarro, A.F. Mars Express : Mission Objectives and Scenario, *Mars Exploration Program and Sample Return Missions*, CNES Proceedings, O11/S1 (101), Paris, February 1999.

[2] Tsuruda, K. PlanetB/Nozomi Mission, *Mars Exploration Program and Sample Return Missions*, CNES Proceedings, O10/S1 (137), Paris, February 1999.

[3] Haberle, R., and D. Catling. A micrometeorological mission for global network science on Mars : rationale and measurement requirements, Planet. Space Sci. 44, 1361-1383, 1996.

[4] Forget, F and co-authors. The Kelvin/Mimas microsatellite project : the case for microwave sounding of the Martian atmosphere, *Mars Exploration Program and Sample Return Missions*, CNES Proceedings, O5/S11 (112), Paris, February 1999.

[5] Chassefière E., and co-authors. Laboratory simulations of the Mars oxidation layer, *Mars Exploration Program and Sample Return Missions*, CNES Proceedings, O6/S3 (111), Paris, February 1999.

ALADDIN: SAMPLE COLLECTION FROM THE MOONS OF MARS, Andrew F. Cheng[1], Olivier S. Barnouin-Jha[1] and Carle M. Pieters[2], [1]The Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Road Laurel, MD 20723-6099, andy.cheng@jhuapl.edu, [2]Dept. of Geological Sciences, Brown University, Providence, RI 02912

Abstract—Aladdin was proposed as a Discovery Mission [1] to obtain samples from the enigmatic Martian moons, Phobos and Deimos, and to return them to Earth. Do the moons share a common origin with Mars, or could they be derived from Martian materials? Are the moons captured primitive bodies from the outer solar system, that may have delivered volatiles and organics to the Martian system? These questions are fundamental to understanding the formation of the Martian system and the early histories of water and other volatiles on Mars.

Aladdin uses an innovative "launch and capture" technique to sample Phobos and Deimos. The spacecraft will launch projectiles targeted at specific geological units on the satellites' surfaces and collect ejecta excavated by the impact on a "flying carpet" at low velocity (~1km/s). Repeated encounters with both moons provide redundant opportunities for sampling. We present an overview of the sampling technique, laboratory tests, and the computational model used to calculate Aladdin's sample yield.

Mission Background

The Aladdin mission will explore and return samples from the two moons of Mars, Phobos and Deimos, whose origins are profoundly mysterious and have important implications for the evolution of the Martian system [1]. To resolve these issues, it is necessary to return samples of both moons to Earth for comprehensive analyses in terrestrial laboratories. With current technology, the amount of sample required to achieve these science objectives using earth-based laboratories can be as small as 3 μg [2]. Aladdin is designed to collect substantially more than this limit. The Aladdin mission will collect the required samples at low cost and low risk, by launching targeted projectiles that impact the moons and eject material These ejecta are collected by the spacecraft on a flexible, fiber maze trap collector as it flies past the target. This collector is subsequently retracted into the Earth return capsule after each shot so that each sample can be analyzed separately. Upon return to Earth, the collector is separated from the spacecraft for hyperbolic re-entry and recovery at the Utah Test and Training Range. Samples are then extracted and analyzed in terrestrial laboratories.

The Aladdin spacecraft will enter a bound, elliptical orbit around Mars that crosses the orbits of both moons repeatedly, affording numerous close flyby opportunities. Each satellite flyby is devoted to remote sensing and/or sample collection. These flybys are at low relative velocities of ~ 1 km/s and ~1.4 km/s at Phobos and Deimos, respectively. To collect samples, the spacecraft launches targeted projectiles at 59 m/s relative to the spacecraft. These impact the target at a speed very slightly greater than the spacecraft velocity of 1 or 1.4 km/s, creating ejecta that are swept up on the collector as the spacecraft flies by the target. The samples are collected at relative speeds of about 1 or 1.4 km/s. The sample collection scenario analyzed below requires the spacecraft to fly by the target at a minimum altitude of 1.5 km above the surface. The projectiles are actually launched some tens of minutes prior to spacecraft closest approach to the target.

Aladdin carries five independent projectile launchers and will sample Phobos three times and Deimos twice. These five independent samples address the geologic diversity of both satellites. The analysis presented below was used to predict the sample size collected by Aladdin on each of its five sampling passes, including effects of spacecraft navigational uncertainties; projectile aiming, timing and launch uncertainties; target moon surface uncertainties; and collector efficiency uncertainties.

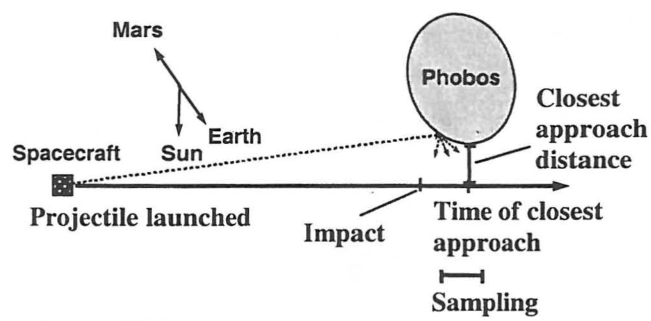


Figure 1. Schematic of sample collection time line.

Sample Return Estimate

Decades of experimental and theoretical studies of cratering mechanics have led to development of scaling rules which have been validated experimentally over many decades in size and impact energy [3-6]. The Aladdin projectile impacts occur in a regime accessible to laboratory experiments and within the realm of applicability of the scaling rules.

Three steps lead to estimates of the sample size that can be captured by the Aladdin spacecraft. First, an end-to-end sample collection model is developed that combines the kinematics of the spacecraft and its projectiles with impact crater and ejecta production scaling rules [3-7], taking account of laboratory measurements of ejecta production from oblique impacts [8-10]. The projectiles and spacecraft velocity (i.e. speed and direction) and the position of the spacecraft relative to the Martian moons are input into the model. The model determines the time and location of impact on the Martian moons, and tracks the position of the excavated ejecta as a function of time. The sample size is determined once the spacecraft intercepts the ejecta.

Second, the end-to-end model results are used to determine optimum targeting conditions at the time of projectile launch while satisfying certain limitations. These limitations arise, for example, from laboratory impact experiments that show when the incidence impact angle (defined relative to the surface normal) significantly exceeds 60 degrees, a zone of ejecta avoidance can form downrange [8-9]. However, recent laboratory experiments show that high speed ejecta, such as captured by Aladdin, are strongly collimated in the downstream direction [10].

Third, a Monte Carlo method statistically assesses the influence of the effect of known uncertainties on the sample size once a nominal spacecraft-sample configuration is established. The known uncertainties include the spacecraft clock, the height of the spacecraft relative to the limb of the targeted moon, the velocity (speed and direction) of the projectiles, the dispersion of the projectiles (for clustered impacts only), the local topographic variations in target surface slope and elevation, the target surface rock cover, and the capture efficiency of the Aladdin collector.

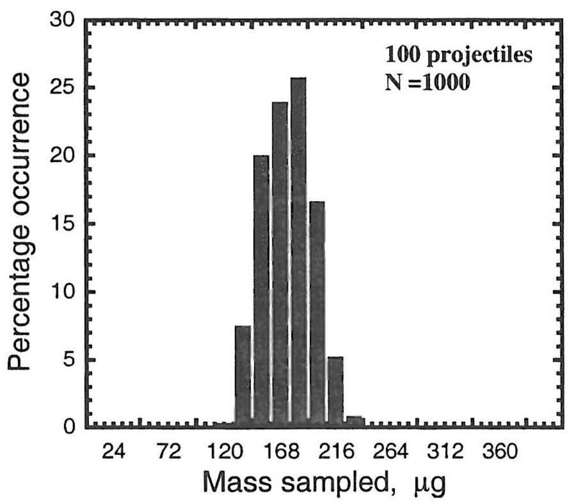


Figure 2. Histogram of sample size captured as a function of percentage occurrence for impact of 100 projectiles, 10-g each, launched into a sand-like regolith on Phobos. A total of 1000 trials analyzed. Results include the influence of downrange ejecta enhancement.

Model results

Preliminary model results have been presented elsewhere [11] and are updated here with the latest experimental data [10]. The model allows optimization of the amount of sample that will be captured by Aladdin, given engineering constraints on the trajectory and/or the sample collection system. For the nominal case (Figure 2), in which 100 projectiles of mass 10 grams each are fired simultaneously, the end-to-end sample return model shows that a mean mass of 175 μg will be captured with each "launch and catch" event. Moreover, in this case the Monte Carlo model predicts a sample mass of 135 μg or greater at the 95% confidence level (see Table 1).

Table 1 also shows that launching a greater number of projectiles reduces the statistical spread of predicted sample size. This is because individual projectiles may impact under favorable or unfavorable conditions, but multiple projectiles average over individual variations. The spread in sample size, 2σ in Table 1, decreases as expected with increased numbers of projectiles. The results obtained from the Monte Carlo model indicate that Aladdin will collect sufficient sample from Phobos and Deimos to exceed comfortably the science requirement of 3 μg. Aladdin samples will revolutionize our understanding of the Martian system.

Table 1. Estimated sample size

Projectile type		Sample size		
number	mass	Mean	2σ	95% confidence
1	1 kg	180.0μg	145.0μg	0.0μg
3	0.33 kg	185.0μg	95.0μg	100.0μg
5	0.2 kg	185.0μg	80.0μg	110.0μg
100	0.01 kg	175.0μg	49.0μg	135.0μg

Acknowledgement. We thank Scott Murchie, Peter Schultz and the Aladdin team for their assistance.

References

[1] Pieters et al. (2000) Concepts and Approaches for Mars Exploration, LPI. [2] Zolensky, M. et al., 2000. *Meteoritics & Plan. Sci.,* 35, 9. [3] Holsapple, K.A. 1993. *Ann. Rev. Earth. Planet. Sci.* 21, 333. [4] Holsapple, K.A. and R.M. Schmidt 1982. *J. Geophys Res.* 87, 1849. [5] Schmidt, R. M. and K.R. Housen, 1987. *Int J. Impact. Engn.* 5, 543. [6] Housen, K.R., R.M. Schmidt and K.A. Holsapple 1983. *J. Geophys. Rev.* 88, 2465. [7] Schultz, P.H. and D.E. Gault, *J. Geophys. Res., 84*, 7669-7687, 1979. [8] Gault, D.E. and J.A. Wedekind, 1978. *Proc. Lunar Planet. Sci. Conf.* VIII, 3843. [9] Schultz, P.H. and D. Gault, 1985. *J. Geophys. Res. 90*, 3701. [10] Schultz, P. H. 1999. *Lunar Plan. Sci. Conf.* XXX, 1919. [11] Barnouin-Jha, O., Cheng, A and von Mehlem, U. 1999. *IEEE Aerospace Conference Proceedings*, Snowmass, CO, track no. 2.204

The Athena Miniature Thermal Emission Spectrometer (Mini-TES) P.R. Christensen[1], G.L. Mehall[1], N. Gorelick[1], S. Silverman[2], and the Athena Science Team. [1]Arizona State University, Dept. of Geology, Tempe, AZ, 85287-1404, [2]Raytheon Santa Barbara Remote Sensing, 75 Coromar Dr, Goleta, CA, 93117.

Introduction: The Miniature Thermal Emission Spectrometer (Mini-TES) is a mature, high-performance infrared remote sensing instrument designed specifically for use on the martian surface. The major objectives of the Mini-TES portion of the Athena investigation are: (1) to map the mineralogy of rocks and soils from the near field to the horizon; (2) to determine the temperature profile and dust, water vapor and water ice abundance of the lower atmosphere; and (3) to determine the thermophysical properties (particle size, induration, and sub-surface layering) of the surrounding terrain. The instrument uses optical, electronic, and mechanical designs with high heritage from the Mars Global Surveyor TES instrument currently in orbit around Mars [1-6]. The Mini-TES will provide infrared spectral image cubes of the full 360° scene around the rover from 50° below to 30° above the horizon at spatial resolutions of 8 and 20 mrad (8 and 20 cm at 10 m distance).

Mini-TES covers the spectral range from 5 to 30 μm (2000 to 333 cm^{-1}) with a spectral resolution of 10 cm^{-1}. An elevation mirror capable of rotating more than 180° is mounted atop the mast between the two Pancam camera heads, reflecting radiation down through the mast and the azimuthal drive system, and into the Mini-TES telescope and interferometer. This system provides a full panoramic view of the surface, the atmosphere, and an internal, full-aperture calibration target. The spectrometer telescope is a 6.35-cm diameter reflecting Cassegrain that feeds a flat-plate Michelson interferometer. The instrument uses an uncooled deuterated triglycine sulfate (DTGS) pyroelectric detector that can operate from –40 to +40° C with no required cooling or heating.

Mineralogic Mapping: The Mini-TES spectrometer covers the 5-30 μm wavelength range, which includes the fundamental molecular vibrational absorptions for virtually all minerals (Fig. 1) [7, 8]. The vibrational energies (wavelengths) of these motions within a crystal lattice occur at fundamental frequencies that are determined by the composition and structure of the mineral. Thus, Mini-TES provides a direct means of identifying the mineralogy of geologic materials including silicates, carbonates (Fig. 2a), sulfates (Fig. 2b), phosphates, oxides, and hydroxides. In silicates the vibrational motions associated with the Si-O stretching modes occur between 8 and 12 μm region, and significant wavelength shifts occur between minerals with chain, sheet, and framework structure. Carbonates, sulfates, and phosphates have an intense absorption features associated with fundamental C-O, S-O, and P-O vibrations respectively that are distinct from those in silicates (for example in the 6-8 μm region for carbonates).

An important objective of the Mini-TES experiment will be the search for mineralogical evidence for ancient aqueous environments. Carbonates form readily in the presence of liquid water and CO_2, and were key constituents of the samples examined by McKay *et al.* [9]. Salts, evaporites, and the minerals formed around hydrothermal springs will be key Mini-TES targets. Hydroxide-bearing minerals such as clays also have distinct spectral features due to fundamental bending modes of OH attached to various metal ions.

Dust coatings and weathering rinds present a potential difficulty for martian *in-situ* compositional measurements. However, studies of terrestrial desert varnish have shown that thermal IR spectral observations can penetrate relatively thick (mean thickness up to ~40-50 μm) layers of these materials. The spectrum of a coating can be successfully separated from that of the underlying substrate using linear mixing models [10]. Thus, using thermal IR spectra the composition of the underlying rock can be determined remotely.

The Mini-TES data will be highly complementary to the both the global data sets obtained by the TES and THEMIS orbiter instruments, and the other *in-situ* instruments in the Athena payload. Mini-TES observations will determine the composition of materials at spatial scales relevant to geologic processes that cannot be studied form orbit, and will provide important ground-truth information about mixing occurring in the global data. By obtaining identical spectral measurements from both rover and orbiter instruments, it will be possible to place the rover results in a global context and to substantially improve the understanding of global compositional units. The Mini-TES data will also be highly complementary with chemical analyses from the APXS and Fe-mineralogy data and Fe^{2+}/Fe^{3+} ratios from the Mössbauer instrument.

Instrument Performance: The Mini-TES has been fully tested and calibrated over the expected operating temperature range from –40° C to +40°. Mini-TES has a signal-to-noise ratio of >350 at 10 μm (1000 cm^{-1}) for a surface temperature of 240 for a single 2-sec integration in 20-mrad mode. Higher SNRs can be obtained by co-adding spectra. The absolute radiance accuracy is ~2%, with a precision of <1%. The instrument weighs 2.4 kg, uses 5.4 W when operating, and is 22 x 16 x 10 cm in size.

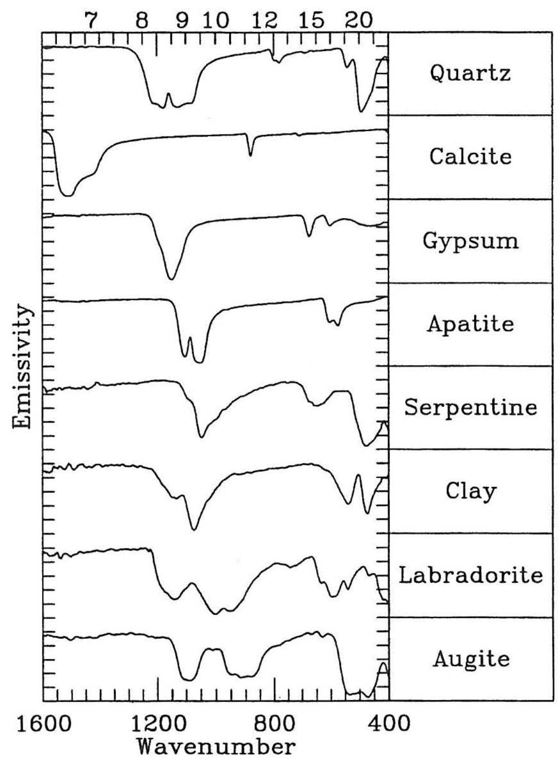


Figure 1. Thermal Infrared laboratory spectra of minerals. These spectra illustrate the discriminability possible with vibrational spectroscopy.

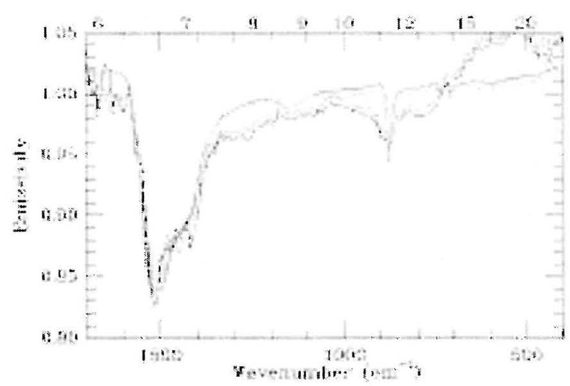
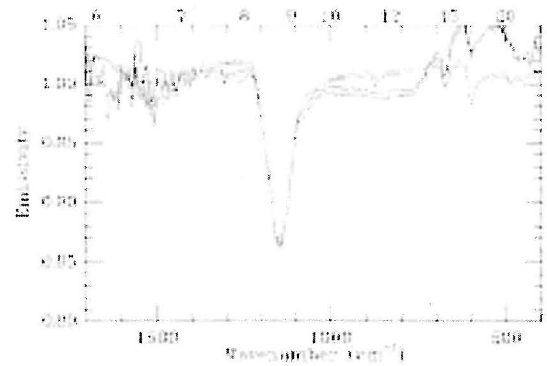


Figure 2a. Mini-TES spectra of calcite rock. Mini-TES spectra, shown in blue/green, were collected in ambient room conditions using the 20 mrad IFOV and 2-second integration. ASU library spectra of calcite are shown in red. Minor deviations at long wavelengths are due to uncorrected downwelling radiation in the room (i.e. blackbody cavity) environment.

Figure 2b. Mini-TES spectra of gypsum rock. Mini-TES spectra, shown in blue/green, were collected in ambient room conditions using the 20 mrad IFOV and



2-second integration. Best-fit deconvolution models of gypsum and minor calcite are shown in red. Minor deviations at long wavelengths are due to uncorrected downwelling radiation in the room environment.

References: [1] Christensen, P.R., et al., *Thermal Emission Spectrometer experiment: The Mars Observer Mission.* J. Geophys. Res., 1992. **97**: p. 7719-7734. [2] Christensen, P.R., et al., *Detection of crystalline hematite mineralization on Mars by the Thermal Emission Spectrometer: Evidence for near-surface water.* J. Geophys. Res., 2000. **105**: p. 9623-9642. [3] Christensen, P.R., et al., *Identification of a basaltic component on the Martian surface from Thermal Emission Spectrometer data.* J. Geophys. Res., 2000. **105**: p. 9609-9622. [4] Bandfield, J.L., V.E. Hamilton, and P.R. Christensen, *A global view of Martian volcanic compositions.* Science, 2000. **287**: p. 1626-1630. [5] Conrath, B.J., et al., *Mars Global Surveyor Thermal Emission Spectrometer (TES) Observations: Atmospheric temperatures during aerobraking and science phasing.* J. Geophys. Res., 2000. **105**: p. 9509-9520. [6] Smith, M.D., et al., *Observations of dust opacity during aerobraking and science phasing.* J. Geophys. Res., 2000. **105**: p. 9539-9552. [7] Farmer, V.C., *The Infrared Spectra of Minerals.* 1974, London: Mineralogical Society. 539. [8] Salisbury, J.W., et al., *Infrared (2.1-25 μm) Spectra of Minerals.* The Johns Hopkins Studies in Earth and Space Sciences, ed. O.M. Phillips, S.M. Stanley, and D.F.Strobel. 1991, Baltimore and London: The Johns Hopkins University Press. 267. [9] McKay, D.S., et al., *Search for past life on Mars: Possible relic biogenic activity in martian meteorite ALH84001.* Science, 1996. **273**: p. 924-930. [10] Christensen, P.R. and S.T. Harrison, *Thermal infrared emission spectroscopy of natural surfaces: Application to desert varnish coatings on rocks.* J. Geophys. Res., 1993. **98**(B11): p. 19,819-19,834.

Infrared Imaging System for Orbital Reconnaissance of Martian Landing Sites. P. R. Christensen[1], G. Mehall[1], S. Silverman[2], and K. Blasius[2], [1]Arizona State University, Tempe, AZ 85284, [2]Raytheon Santa Barbara Remote Sensing (SBRS), 75 Coromar Dr., Goleta, CA 93117.

Introduction: One of the objectives of a landing site reconnaissance orbiter would be to determine and map the rock distribution and surface properties of extensive areas of the Martian surface for hazard characterization. We propose using an infrared imaging system to: (1) map the thermal inertia of the surface at high spatial resolution; and (2) determine surface rock abundance using multi-wavelength measurements. The rock abundance would be determined using a model of thermal emission from a surface composed of rocks and soil at different temperatures [1,2,3]. [Christensen, 1982; Christensen, 1986; Golombek et al., 1997]. These models use the predicted temperature difference between rocks and fines to model and match the observed non-blackbody spectral properties. Spectral data from the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) and the 2001 Surveyor Orbiter Thermal Emission Imaging System (THEMIS) instruments will be used to determine the surface emissivity and refine the rock abundance modeling. The thermal inertia would be derived using pre-dawn measurements; these data would be used to characterize the average surface properties and map dust distribution, which can not be determined from visible images.

The IR sensor concept, first presented in a White Paper [4], would provide rock and thermal inertia maps at significantly higher spatial resolution (10 m) than either TES (3 km) or THEMIS (100 m), with higher performance and complete equatorial coverage. This instrument would be complementary to the visible sensor on a Large Aperture Reconnaissance Orbiter. The primary contributions from the infrared sensor would be: (1) determination of rock abundance and soil grain size with significantly increased spatial coverage than obtained from the high-resolution visible imager; (2) validation of existing global rock abundance maps derived from thermal IR remote sensing data by direct comparison with simultaneous observation of rocks using the visible system; and (3) determination of the soil grain size.

The performance estimates made below are based on our experience with previous instruments, including the Mars Observer TES, the Mars Global Surveyor TES, the '01 Orbiter THEMIS, and the Lander Mini-TES which may be launched in '03 or '05. Data and performance models from the SBRS Landsat Thematic Mapper, TRMM/VIRS, and MODIS visible and infrared imaging systems have also been incorporated.

HIGH RESOLUTION IR IMAGER FOR A LARGE APERTURE ORBITAL TELESCOPE:

Measurement Requirements.

1) better than 10 m ground resolution

2) Two IR bands separated by at a factor of two in wavelength to provide sub-pixel temperature component identification.

3) > 5 kilometer cross-track coverage.

4) <1.0 °K noise equivalent delta temperature (NEDT) at surface temperature of 170 K.

5) Complete coverage of the Martian surface between 30° S and 30° N latitude.

Our design concept is based on several assumptions about the telescope system shared with the visible sensor. These include:

1) Circular, 1-meter aperture telescope.

2) 2 meter focal length f/2 optical system.

3) Uncooled (300 K) telescope; aft optics cooled to 150 K.

4) 300 km altitude orbit.

5) 3.1 km/sec ground velocity.

6) 2° cross-track field of view.

7) 50% optical throughput, including obscuration, beamsplitter, and IR imager filter transmission, at a wavelength of 10 μm.

We also assume a typical low Mars orbit ground velocity of 3.1 km/sec.

Sensor Characteristics.

A schematic diagram of the sensor is shown in Figure 1. The thermal energy from the 1-m aperture telescope will be separated from the visible energy using a beamsplitter. An internal rotating mirror will allow views of Mars, space, and an internal calibration target. The IR sensor will be a self-contained module with its own power conditioning, data readout, data interface, and cooler electronics subsystems. Commands, data, and power lines would connect directly to the spacecraft, providing system redundancy with the visible imager.

The sensor design concept includes the following:

1) HgCdTe IR detectors actively cooled to 60 K.

2) Two IR bands centered at 7.4 μm (7.0-7.8 μm) and 13.3 μm (13.0-13.6 μm).

3) PV MgCdTe for both the bands.

4) Two 640 pixel linear arrays with 53 μm pitch pixels. Total of 1280 cross-track pixels.

5) 12 bit A/D converter.
6) 60% detector quantum efficiency.
7) 25% of background limited performance (BLIP) in 7.4 μm band.
8) 5% of background limited performance (BLIP) in 13.3 μm band.
9) 1/f noise controlled using a DC restore function viewing space for 5 sec every 60 sec.
10) Calibration is provided using an internal calibration blackbody.
11) A flip mirror is used to provide periodic (approximately once every 2 minutes) views to space port and the internal reference blackbody.
12) No internal data compression.
13) Data compression and formatting using spacecraft computer

Derived IR Sensor Parameters.
1) 10.25 km (1.96°) cross-track field of view
2) Diffraction limit at 13 μm = 5 meter
3) MTF at Nyquist: along-track =0.22; cross-track = 0.49
4) 8 meter pixel IFOV ground resolution, consistent with the diffraction limit of the telescope.
5) 2.5 msec dwell time
6) Equivalent D* of 8.3 x 10^{10} in the 7.4 μm band.
7) Equivalent D* of 7.1 x 10^{10} in the 13.3 μm band.
8) 9.8 Mbit/sec output data rate.

Estimated Mass, Power, and Size. The mass of the IR sensor has been estimated at 20kg, including a 20% mass margin, using comparable subsystems of the Mars 2001 Orbiter THEMIS instrument: focal plane and electronics. An active cooler with mass 10kg has been added.

The power requirement of the sensor has been estimated at 35W, again using the THEMIS instrument, with the following assumptions. (1) the power required for the power supply, command, and data interface electronics are comparable to the equivalent THEMIS electronics; (2) the active cooler requires 20 W.

The size of the IR sensor has been estimated to be 20 cm x 15 cm x 20 cm.

Predicted IR Instrument Performance

	7.4 μm Band		13.3 μm Band	
Surface Temp.	170 K (night)	270 K (day)	170 K (night)	270 K (day)
NEDT	1.02 K	0.06 K	0.93 K	0.32 K
SNR	15	680	48	342
Ground Res.	8 m	8 m	8 m	8 m
Swath (km)	10.25	10.25	10.25	10.25

References: [1] Christensen, P.R. (1982) JGR, 87, 9985-9998. [2] Christensen, P.R. (1986) Icarus, 68, 217-238. [3] Golombek, M.P. et al. (1997) JGR, 102, 3967-3988. [4] Christensen, P.R. et al. (Feb. 9, 2000), Infrared Imaging Systems for a Mars Reconnaissance Orbiter, White Paper prepared for the Jet Propulsion Laboratory by Arizona State University and Raytheon SBRS.

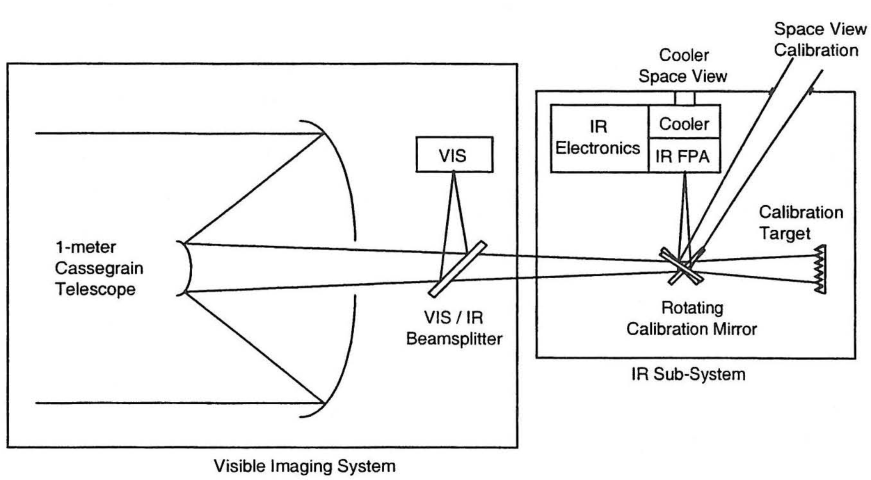


Figure 1. Schematic Diagram of IR Sensor Subsystem and Large Aperture VIS Sensor System

THE MARTIAN ATMOSPHERIC GRAIN OBSERVER (MAGO) FOR IN SITU DUST ANALYSIS. L. Colangeli[1] and the MAGO International Consortium, [1]Osservatorio Astronomico di Capodimonte, Via Moiariello 16, 80131 Napoli – Italy, e-mail: colangeli@na.astro.it

Introduction: The properties of dust dispersed in the Martian atmosphere, its dynamic structure and evolution and its interaction with gas and surface are subjects of strong interest in Mars science. Dust storms, dust devils and the dust "cycle" have been identified and studied by past remote and in situ experiments, but little quantitative information is available on these processes, so far. The airborne dust contributes to determine the dynamic and thermodynamic evolution of the atmosphere, including the large scale circulation processes and it impacts on the climate of Mars. Moreover, aeolian erosion, redistribution of dust on the surface and weathering processes are mostly known at a qualitative level. It results that to measure the amount, mass/size distribution and dynamical properties of solid particles in the Martian atmosphere, as a function of time, is a fundamental step to shade light on the airborne dust evolution and, more in general, on the atmospheric processes. In this frame it is evident the need of the implementation of experiments dedicated to study directly atmospheric dust. The MAGO (Martian Atmospheric Grain Observer) experiment is aimed at providing direct quantitative measurements of mass, size and shape distributions, as well as dynamic behavior of atmospheric grains, a goal that has never been reached so far.

Scientific rationale: Dust is permanently mixed with the other Martian atmospheric components at all times, even if with variable abundance. Airborne dust contributes to determine the climate of Mars and, probably, it played a role in the past evolution of the climate and the surface characteristics. The dust is relevant in the dynamic and thermodynamic evolution of the atmosphere, including the large scale circulation processes. The amount and distribution of airborne dust affects the thermal structure and circulation of atmosphere on diurnal, seasonal and annual timescales. Dust blown in the atmosphere absorbs and scatters solar radiation and becomes a relevant thermal source. Observations suggest that Mars presents adjacent continents with different thermal characteristics which contribute to drive circulation on regional scales. However, the dust and gas transportation mechanisms are not yet well characterized.

The so-called "dust-cycle" is correlated to the seasonal variations of carbon dioxide and water vapor. Atmospheric grains may act as catalysts for the condensation of H_2O and CO_2 in the atmosphere. On the other hand, the surface pressure and the CO_2 variation somehow control the occurrence of dust storms, on both regional and global scales. Last but not least, it looks that dust storms ignition requires a feedback from atmospheric dust, in terms of dynamics and heating.

Aeolian erosion, redistribution of dust on the surface and weathering mechanisms couple surface and atmospheric evolution. The exchanges occur in the turbulent boundary layer, extending up to about a few hundred meters from the surface. So far, only qualitative information has been obtained on dust injection, transport and removal mechanisms. These mechanisms are driven by the wind intensity and the grain size distribution. Models predict that grains of about 100 μm are raised and blown off (saltation) for friction velocity $u \sim 1.5$ m s^{-1}; while u must be larger than ~ 4 m s^{-1} to lift 1 – 10 μm grains. Actually, the Viking Lander 1 experienced a great dust storm with wind velocities up to 10 m s^{-1} (at about 1.6 m height). This is compatible with above mentioned u values.

The so-called "dust devils" are associated to vortical winds capable to lift surface dust and may extend up to 1 – 2 km in altitude. Several of these vortices were identified by the Viking Lander and have been, more recently, observed by Mars Pathfinder. In this last case, one vortex every two days crossed the Pathfinder site, on average. Interpretation of images taken at different colors has shown that dust columns ranged from 15 to 80 m in width, 46 to 350 m in height and passed at a velocity between 0.5 m s^{-1} and 4.5 m s^{-1}. The development mechanism of dust devils is largely undetermined.

The previous considerations demonstrate that dust on Mars participates to several atmospheric evolutionary processes. However, the data accumulated so far from remote observations and in situ measurements are rather poor. Mariner 9 observations during the 1971-1972 dust storm were used to derive information about the size distribution of grains, but they cover a limited size range and need further confirmation. Dedicated measurements on Mars Pathfinder gave only qualitative information on the dust coverage with time.

A more systematic analysis of dust by in situ measurements is, then, very important. Direct quantitative measurements of grain mass, size and shape distributions, as well as dynamic behavior, have never been

achieved so far. The determination of such properties will now be possible by the MAGO experiment.
MAGO is aimed at measuring *the cumulative dust mass flux* and *the dynamical properties of single intercepted particles* and their variations with time. These objectives are in line with the request of environmental measurements about dust and contribute to the definition of the relations between aeolian transport (dust properties and velocity) and atmospheric properties.
Beside their intrinsic scientific value, the measurements by MAGO have a crucial role in terms of the identification of hazard conditions for missions dedicated to the exploration of Mars. Actually, MAGO data can be used to identify situations in which the dust amount may become dangerous for the degradation/survival of elements sensitive to dust deposition and, in a wider perspective, for the human exploration of the planet.

Instrument characteristics and performances: The MAGO instrument combines three types of sensors to monitor simultaneously the dust cumulative flux (Micro Balance System, MBS) and the single grain dynamic parameters (Grain Detection System, GDS, + Impact Sensor, IS). The sub-systems are similar to or derived from concepts already developed for the GIADA experiment on board the ESA-ROSETTA space mission and, therefore, benefit of the development program already carried on for this application.
The accumulation of grains on a MBS sensing device allows us to monitor the total mass of grains intercepted by the sensor and the dust mass flux vs. time is derived. This result provides a direct information about the evolution of dust content, following short and long term modifications of the Martian atmosphere. Three MBS's, pointing in different directions, are used to investigate directional effects of dust motion. One of them points in the zenith direction to measure the flux of grains falling on the surface, an important information related to the transportation and redistribution of dust on the surface.
The determination of the dust dynamic properties (momentum and velocity vs. grain mass) is obtained by the combined detection of single particles by the GDS + IS sub-systems, working in cascade. The first stage (GDS) measures the velocity of each grain entering the sensitive area of the instrument, but it does not perturb the grain dynamics. The momentum of the grain is measured by the second stage (IS), through the impact of the incoming grain on a sensing plate, and the grain mass is derived. Information about the shape and/or size of the passing grain may be derived by the GDS, whose detection signal is related to the scattering/reflection properties of the detected particle. The detection of a large number of events in time allows us to have a statistical information and to determine velocity/momentum properties vs. mass (and possibly size/shape). The counts of events detected by the GDS+IS system are also a complementary information with respect to the data provided by the MBS sensors. As a baseline, the GDS+IS sensors are pointed in an horizontal direction.
The sensitivities of the MAGO sensors, according to the present status of the development, are summarized in Table 1.

GDS	
Sensitivity	Particle diameter > 10 μm (possibly > 2 μm, TBC) Particle velocity < 300 m s^{-1}
Dynamic range	4 decades (TBC) on the signal
IS	
Sensitivity	Momentum > 10^{-11} Ns
Dynamic range	6 decades on the signal
MBS	
Sensitivity	Cumulated mass > 10^{-10} g
Dynamic range	Up to 10^{-5} g

Table 1. Performances of MAGO sensors

According to the present design, the MAGO requirements are: mass ~ 1.45 Kg; volume envelope ~ (90 x 180 x 90) mm^3; total power consumption at normal operation ~ 6.1 W.
These data demonstrate that MAGO is a versatile instrument that can be easily integrated also in small payloads targeted to the exploration of the Martian dust environment.

HABITAT OPTIONS TO PROTECT AGAINST DECOMPRESSION SICKNESS ON MARS. J. Conkin, National Space Biomedical Research Institute/Baylor College of Medicine, One Baylor Plaza, NA-425, Houston TX 77030-3498, USA (jconkin@ems.jsc.nasa.gov).

Men and women are alive today, although perhaps still in diapers, who will explore the surface of Mars. Two achievable goals to enable this exploration are to use Martian resources, and to provide a safe means for unrestricted access to the surface. A cost-effective approach for Mars exploration is to use the available resources, such as water and atmospheric gases. Nitrogen (N_2) and Argon (Ar) in a concentration ratio of 1.68 / 1.0 are available, and could form the inert gas component of a habitat atmosphere at 8.0, 9.0, or 10.0 pounds per square inch absolute (psia).

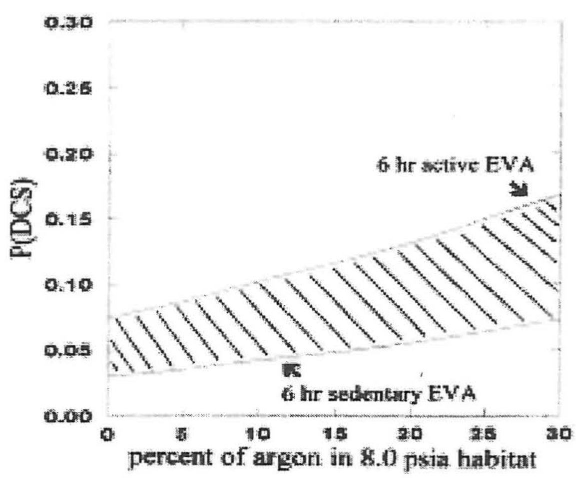
The habitat and space suit must be designed as an integrated, complementary, system: a comfortable living environment about 85% of the time and a safe working environment about 15% of the time. A goal is to provide a system that permits unrestricted exploration of Mars. However the risk of decompression sickness (DCS) during the extravehicular activity (EVA) in a 3.75 psia suit after exposure to either of the three habitat conditions may limit unrestricted exploration.

The choice of a breathing atmosphere for the Mars habitat is a problem with multiple variables driven by engineering, medical, and operational requirements. The engineering drivers are to use the lowest possible habitat pressure, which conserve limited resources, use inert gases in the Martian atmosphere without costly processing, and use a 3.75 psia soft suit with 100% oxygen (O_2). The medical drivers are to provide adequate alveolar O_2 pressure in the habitat and suit, do not increase the risk of fire, and incur no DCS that cannot be treated effectively on Mars. An operational driver is to provide for unlimited access to the surface without time-consuming prebreathing. The engineering, operations, and medical community will evaluate and "trade" various options until a safe system is devised.

My assumption is that an automated system sent to Mars before a manned flight will extract and store the thin Martian atmosphere that exerts a total pressure less than five mmHg. This pressure is equivalent to the pressure at about 110,000 feet above the Earth. The atmosphere is composed of 95.7% Carbon dioxide, to be used to make O_2, 2.7% N_2, and 1.6% Ar [1], a ratio of 1.68 N_2 to 1.0 Ar. From an engineering standpoint, the preference would be not to separate the inert gases into different containers; this takes too much energy and technology. Therefore the atmosphere for the habitat would have N_2 and Ar at the ratio already in the atmosphere with the balance of O_2 to achieve an acceptable total pressure.

An analysis was performed to evaluate the risk of DCS since a significant proportion, about 25%, of a trinary breathing gas in the habitat would contain Ar. Based on assumptions about Ar in hypobaric decompressions, I conclude that the presence of Ar significantly increases the risk of DCS. Constrained as I am by this initial cost-effective approach, the risk is significant even with the best habitat option: 2.56 psia O_2 (32%), 3.41 psia N_2 (42.6%), and 2.20 psia Ar (25.2%).

The figure illustrates a process rather than provides accurate quantitative information on DCS risk at this time. It shows a heuristic risk-to-benefit analysis of Ar as part of the breathing environment in an 8.0 psia habitat prior to an EVA in a 3.75 psia suit. The balance of the inert gas component is N_2 while the O_2 concentration is always 32%. There is a compromise between DCS risk, expressed as the probability of DCS [P(DCS)], and various concentrations of Ar in the 8.0 psia habitat. In this simulation, a 30 min prebreathe is included as part of an operational period of suit purge and leak checks prior to the EVA.



The upper curve shows the estimated risk for DCS given that work in ambulating astronauts is done. The lower curve is for the same ambulating astronauts but no work is done. The contribution of exercise (work) toward DCS risk is significant. Walking and working in the 3/8th gravity of Mars influences the risk of DCS and, unfortunately, this important variable is not yet understood. It is likely that the better estimate of DCS risk is along the lower curve, with worse-case being reflected in the upper curve.

The magnitude of the DCS risk depends on the two assumptions used to deal with Ar, which are suspect. It appears that the benefit of using the cost-effective 1.68 N_2/1.0 Ar ratio at 25.2% Ar is associated with some risk of DCS, between 6% and 15%. However the absence of Ar provides for the lowest risk of between 3% and 7%. Additional details are found in [2] and [3].

I conclude that this cost-effective approach, which is the first approach that would be requested by a Mars Program Office, would drive a risky EVA program in terms of DCS. This conclusion needs to be challenged with empirical data from well-designed human trials under various options for a habitat atmosphere. It is not possible to confidently extrapolate all the way to Mars with what little is known about the risks of using Ar. A test program, which includes appropriate facilities, is needed if Ar is seriously considered as a breathing gas in a Mars habitat.

The single most critical constraint to safe and effective EVAs is the current limit placed on the O_2 concentration in the habitat atmosphere. If the O_2 concentration can not be increased, then several hours of prebreathing 100% O_2 from a mask, or while in the suit, or in a special prebreathe room would be necessary. Also, a higher suit pressure, or a combination of other important variables such as limited exposure time on the surface, or exercise during prebreathe would be necessary to reduce the risk of DCS to an acceptable level. The acceptable level for DCS risk on Mars has not yet been determined. Mars is a great distance from Earth and therefore from primary medical care. The acceptable risk would necessarily be defined by the capability to treat DCS in the Rover vehicle, in the habitat, or both.

References: [1] Moore P. (1998) Patrick Moore on Mars. Cassell: London, p. 143. [2] Conkin J. et al. (1996) Aviat Space Environ. Med., 67, 176-83. [3] Conkin J. (2000) NASA Technical Memorandum 2000-210188, Johnson Space Center.

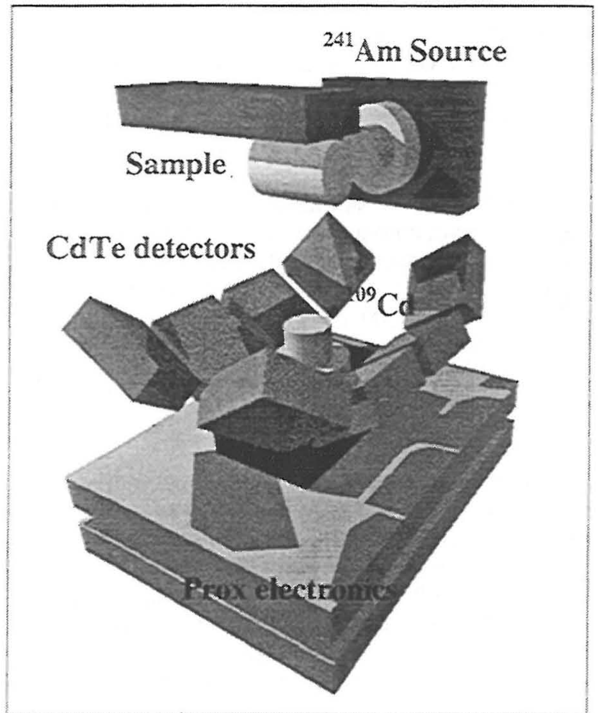
MA_FLUX: THE X-RAY FLUORESCENCE EXPERIMENT INSIDE THE IPSE LABORATORY.

B. Cordier[1], G. Manhes[2], R. Bianchi[3], A. M. Di Lellis[3], P. Masson[4], D. Chambellan[5], C. d'Uston[6], S. Espinasse[3], C. Federico[7], M. Preite Martinez[8],
[1]CEA/DAPNIA/Service d'astrophysique, CEA-Saclay, France, [2]Institut de Physique du Globe de Paris, France, [3]Istituto di Astrofisica Spaziale CNR, Rome, Italy, [4]Université Paris Sud, Orsay, France, [5]CEA/DAMRI/Service d'application des rayonnements, CEA-Saclay, France, [6]CESR, Toulouse, France, [7]Universita di Perugia/Dip. Scienza della Terra, Italy, [8]Universita di Roma"La Sapienza"/Dip. Scienza delle Terra, Italy.

The IPSE laboratory will analyse samples collected by the robotic drill. Inside the laboratory each sample will be presented to different complementary experiments. The Ma_flux experiment is devoted to the geochemistry analysis of the sample.

The Ma_Flux experiment will estimate the abundance of the major and trace chemical elements of the Martian samples using simultaneously the gamma scattered method and the X-ray fluorescence technique.

The instrumental innovation is based on a new generation of hard X-ray detectors (Cadmium Telluride - CdTe). This new generation of detector does not need any cooling and offers a good energy resolution and a good efficiency up to 150 keV. The Ma_Flux detection plan is composed by 128 individual CdTe detectors. Coupled with two gamma-ray sources for the excitation system (241Am, 109Cd), this instrument will be able to investigate the interior of the samples. By analysing at different energies and at different angles the Compton and Rayleigh scattered photons, it will be able to estimate the abundance of the major elements. By analysing the hard X-ray fluorescence features, this system should evaluate the chemical composition of the trace elements within a few ppm.



Ma_Flux concept

DETECTION AND CHARACTERIZATION OF MARTIAN VOLATILE-RICH RESERVOIRS: THE NETLANDER APPROACH. F. Costard[1], J.J. Berthelier[2], and the GPR team, G. Musmann[3], M. Menvielle[2], and the MAGNET team, P. Lognonné[4], D. Giardini[5], B. Banerdt[6], and the NL-SEIS team, A-M Harri[7], F. Forget[8], and the ATMIS team. [1]UMR 8616, CNRS, Orsay, France, fcostard@geol.u-psud.fr, [2]C.E.T.P., UMR 8639, Saint-Maur, France, [3]TUBS-IMG, Braunschweig, Germany, [4]IPGP, Saint Maur, France, [5]ETH, Zurich, Switzerland, [6]JPL, Pasadena, USA, [7]FMI, Helsinki, Finland, [8] LMD, Paris 6, Jussieu, France,

Introduction: Geological and theoretical modeling do indicate that, most probably, a significant part of the volatiles present in the past is presently stocked within the Martian subsurface as ground ice, and as clay minerals (water constitution). The detection of liquid water is of prime interest and should have deep implications in the understanding of the Martian hydrological cycle and also in exobiology. In the frame of the 2005 joint CNES-NASA mission to Mars, a set of 4 NETLANDERs developed by an European consortium is expected to be launched between 2005 and 2007 [1]. The geophysical package of each lander will include a geo-radar (GPR experiment), a magnetometer (MAGNET experiment), a seismometer (SEIS experiment) and a meteorological package (ATMIS experiment). The NETLANDER mission offers a unique opportunity to explore simultaneously the subsurface as well as deeper layers of the planetary interior on 4 different landing sites. The complementary contributions of all these geophysical soundings onboard the NETLANDER stations are presented.

Water reservoirs: The presence of valley networks and outflow channels [2] suggests that liquid water has been present on the surface throughout most of Martian history [3, 4]. Morphological studies (e.g., rampart craters, periglacial features, terrain softening), theoretical modeling [5, 6] and analysis of SNC meteorites, both strongly suggest that a large amount of volatiles (H_2O, CO_2, chathtrates) might still stored within the Martian megaregolith as a deep and global underground ice [5, 7, 8, 9]. Theoretical estimates of the ground ice thickness range from 3 to 7 km near the poles to between 1 and 3 km near the equator [5, 10]. Due to sublimation processes and to the porous nature of the megaregolith, the ground ice table is covered by a dry layer of 100 m to 1 km thick. It is expected that, under the ground ice, liquid water exist, at least at middle latitudes. The depth of the 0°C isotherm could be reduced by both pressure and solute effects [6].

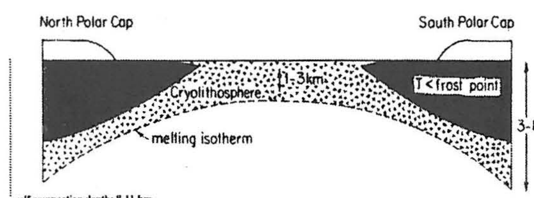


Fig. 1: The Martian ground-ice (from Squyres et al., 1992).

Geophysical studies of water reservoirs: On Earth, several techniques are available to explore the structure and the nature of the subsurface; these are passive soundings such as magneto-telluric techniques, active electromagnetic soundings, and passive or active seismic methods. Each of them has its own advantages and limitations and the choice is mostly guided by the range of depths to be explored, the needed spatial resolution and the horizontal extent to be covered. We therefore propose to fly on each of the 4 landers of the NETLANDER mission a set of geophysical instruments to explore the first few kilometers of the subsurface with, as major objectives, the detection of possible water rich layers and the characterization of the main features of the geological structures of the superficial planetary crust. The study of the subsurface, including the ground ice, will be actively performed with a geo-radar, and passively with the magnetometer and seismometer. These geophysical instruments will probe the uppermost kilometers of Mars to search for signatures of ice reservoirs and possible transition to liquid water layers. Simultaneously geophysical studies will give access to the main structural and geomorphological features of the subsurface.

The major goals of our experiment will thus be:

- to determine the presence of ground ice layers, compare their depth and thickness to the results inferred from the analysis of rampart craters and detect the possible existence of liquid water layers at large depths
- to determine the characteristics of the volatile rich layers of sedimentary deposits and/or lava flow that will provide new insight into sedimentation processes and/or volcanic episods.
- to understand the association between the surface morphology and the deep layers of ground ice

Geo-radar investigations (GPR experiment): Due to its relative simplicity, the technique of HF ground penetrating radar appears as a unique tool for planetary exploration. We plan to use a set of 3 monopole electric antennas angularly spaced by 120° and 3 magnetic receiving antennas to determine the directions of the returning electromagnetic waves and, therefore, obtain a 3D imaging of the subsurface. Three monopole electric antennas powered by a 10 W transmitter are used to transmit electromagnetic waves at a central frequency of 2 MHz with linear as well as planar (circular or elliptical) polarization. Two electric and three magnetic components of the electromagnetic waves returning to the radar are measured. The subsequent signal analysis performed on these data will allow to retrieve the direction of propagation of the returning waves and thus the direction of the reflectors while their distance is obtained from the propagation time of the waves [11]. The possibility to operate with various polarization schemes provides a capability of significant interest for the GPR instrument since it will allow to study in more details the backscattering properties of the reflectors in the subsurface.

A numerical simulation has been performed to assess the performances of the GPR instrument. The model subsurface consisted in a number of layers with depth, thickness and physical properties representative of the expected average Martian subsurface. Results are consistent with the simpler calculation which were performed to design the radar and show that a liquid water interface should be detectable at depths of approximately 2.5 km. During nighttime we foresee to operate the GPR instrument in a passive mode in order to receive the waves emitted by the MARSIS radar on-board the MARS EXPRESS orbiter.

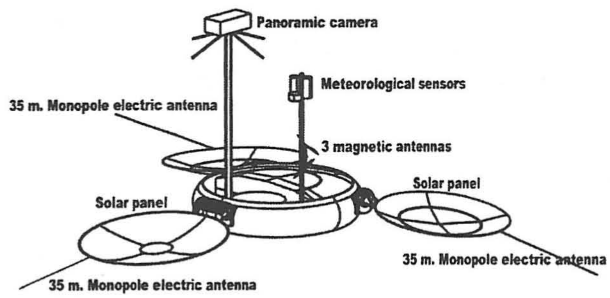


Fig. 1: baseline configuration of the geophysical soundings.

Electromagnetic soundings (MAGNET experiment): The magnetometer experiment consists of a net of identical ultra small low noise and light triaxial vector fluxgate magnetometer sensor, with a resolution of 0.025 nT. The magnetometer sensor is placed at the surface of Mars, outside the lander, by means of a light deployable boom [12]. The attitude of the vector components of each triaxial fluxgate sensors will be known with an absolute accuracy of few tenths of a degree in both vertical and horizontal directions. The impedance of the internal structure will be deduced from the ratio of the vertical component of the magnetic field and the horizontal gradients of its horizontal component. With simultaneous recordings from three stations or more available, the impedance will be estimated from the frequency-wave vector spectrum of the electromagnetic field using a high-resolution method developed by Pinçon et al., [13]

Below 1-2 km, the determination of the mean resistivity profile will be done with the magnetometer. This will allow the determination of the thickness of the resistive ground ice, and will provide information about the presence (or absence) of liquid water under the ground ice. As the resistivity of the permafrost is very high, the presence of liquid water at the bottom of the ground ice will then correspond to a decrease of the resistivity by two or more orders of magnitude. Simulations have been made with models of resistivity distribution within the Martian ground ice. The model resistivity profiles have been extrapolated from laboratory measurements on water saturated porous rocks for temperature ranging from – 25°C to + 5°C [14]. The measurements have been made on a sandstone sample of 18% porosity saturated with salted water of conductivity 1 S/m. Two profiles corresponding to typical high- and low-latitude situations have been considered. The obtained results make clear that knowing the apparent resistivities within a precision of about 16% for frequencies ranging from 10 to 0.001 Hertz allows to evidence a conductive layer associated to liquid water below the permafrost, and to get relevant estimates of its depth and integrated conductivity.

Seismological investigations (SEIS experiment): A last piece of information will be done with the seismometer. The output used will be those of the BRB Short period 3 axis seismometer, which will record seismic signals in the band 0.05-50 He with a resolution bettor than 5 10^{-9} ms^2/Hz $^{1/2}$ [15]. The body wave will then be the subject of site effect (see Horwarth et al., 1980 for the use of this method on the Moon) and the analysis does not need the location of the seismic source, which will allow the use of seismic signals released by the regional quakes. Two parameters will be searched: the first will be the position of the subsurface discontinuities, the latter being smoothed by the magnetic inversion, mostly sensitive to the resistivity jumps. The second will be the seismic high frequency attenuation, which is very sensitive to the water content at depth below the 0°C isotherm.

Interaction regolith/atmosphere (ATMIS experiment): Netlander also include a meteorological package (ATMIS) which will provide some observations of interest to study the climate water cycle. The local relative humidity during warm hours will be monitor day after day from the four landers by the Humicap sensors. Clouds and condensat will be observed by the Optical Depth Sensor (ODS) and the camera. Such observations should allow us to constrain the diurnal and seasonal exchange between the regolith and the atmosphere (adsorption and condensation) as well as the vertical distribution of the water vapor above the Lander.

A complementary approach: The results of electromagnetic and ground penetrating radar ground ice investigations are clearly complementary, and combining their results would greatly improve our knowledge of the permafrost structure at the NETLANDER landing sites. On one hand, radar measurements are likely to provide quite clear information on the thickness of the uppermost very resistive layer of the ground ice. On the other hand, electromagnetic soundings will provide information on the depth of the conductive layer associated with liquid water, if any. Besides, electromagnetic soundings will provide information on the thickness and conductivity of this layer.

References: [1] Harri A-M et al. *Adv. Space Res.*, 23, No 11. [2] Baker, V.R., (1982) The channels of Mars. 198 pp., Univ. of Texas Press. [3] Masursky et al., 1977. *J. Geophys. Res. 82,* 4016-4038. [4] Carr M.H., 1986. *Icarus 68,* 187-216. [5] Squyres S.W. et al. (1992) in Mars Book Univ. of Arizona Press. [6] Clifford, S.M. (1993) *JGR 98,* E6. 10973-11016. [7] Rossbacher, L.A. and S. Judson, (1981) *Icarus, 45,* 25-38. [8] Kuzmin, R. et al. (1989) *Solar System Res. 22,* 121-133. [9] Costard, F. (1989). Earth, Moon and Planets. 45: 265-290. [10] Fanale F.P., et al. (1986) Icarus, 67, 1-18. [11] Berthelier J.J. et al. *Planet. Space Sci.*, 2000, in press. [12] Menvielle M. et al., *PSS,* 2000, in press. [13] Pinçon J.L. et al. PSS, 2000, in press. [14] Guichet, (1998), Etude des propriétés Géophysiques du pergélisol martien, Mémoire de DEA, IPGP. [15] Lognonne Ph. et al., *PSS,* 2000, in press

THE NETLANDER MISSION: A GEOPHYSICAL NETWORK ON THE MARS SURFACE. J. L. Counil, O. Marsal, F. Rocard, Ph. Lognonne, A. M. Harri, and all the NETLANDER Team.

The NETLANDER mission aims at deploying on the surface of Mars a network of four identical landers which will perform simultaneous measurements in order to study the internal structure of Mars, its sub-surface and its atmosphere. It will then be the first mission of its kind.

The NETLANDER program is conducted in a European and international co-operative framework under the leadership of the French Space Agency, CNES. A NETLANDER consortium composed of France, Finland, Germany, Belgium has been established in 1999. The objective is to have the NETLANDER mission ready for launch in 2005 and the study payload for phase B, composed of nine instruments, has been selected in April 2000:

SEIS: Seismometer; PI: Ph. Lognonné, IPG, France
ATMIS: Atmospheric measurements, PI: A.M. Harri, FMI, Finland
PANCAM: Panoramic camera; PI: R. Jaumann, DLR, Germany
ARES-ELF: Atmospheric electricity sensor, J. J. Berthelier, CRPE, France
NEIGE: geodesic and ionospheric measurements
SPICE: Soil properties measurements, T. Spöhn, univ Münster, Germany
GPR: Penetrating Radar, PI: J. J. Berthelier, CRPE, France
MAGNET: Magnetometer, PI: G. Müsmann, Univ Brausweig, Germany
MICROPHONE: University of Berkeley and Planetary Society

Mission scenario

The NETLANDER mission has to take into account the on-going re-architecture of the MARS exploration program and several key elements of the following scenario will have to be confirmed when the new architecture is available:

- The 4 NetLander probes are launched in 2005: during the launch and the cruise phase to Mars, they are attached to the carrier that provides them with the necessary ΔV.;
- On arrival at MARS, they are ejected from the carrier according to a sequence depending on the choice of their landing sites. In order to allow precise orbit determination during the NetLander separation, 4-days interval is necessary between two lander separations. Hence, the separation sequence starts two or three weeks before arriving at Mars;
- After the coast phase and the atmospheric entry phase, the probes land on Mars. The landers are initialised and their antenna is deployed to begin exchanging data and commands with the Earth,
- During their operations on the surface of Mars, the NetLander probes communicate with the Earth via a Mars relay orbiter (Mars Express or any telecom satellite including the carrier).

Landing sites

The choice of landing sites will result from a compromise between scientific objectives and technical constraints. The technical constraints are mainly the co-ordinates (reachable from the orbit), the altitude (a too high altitude prevents the parachutes to work properly), the site characteristics (slopes, rocks percentage, ...). The scientific requirements are primarily driven by the objectives of network science, which are expressed in terms of network shape, latitudinal and longitudinal coverage, distances between the stations. Each network experiment (seismology, magnetism and meteorology) has its own requirements. In addition, the network must be robust to the accidental loss of one NETLANDER during the cruise, at landing or during operations at MARS. Sites of specific interest have also been identified (e.g. sites where water reservoirs can be expected at low depths) and should be as much as possible included in the network.

The final configuration that can impact the NETLANDER design is expected to be settled at the end of phase B.

NetLander design

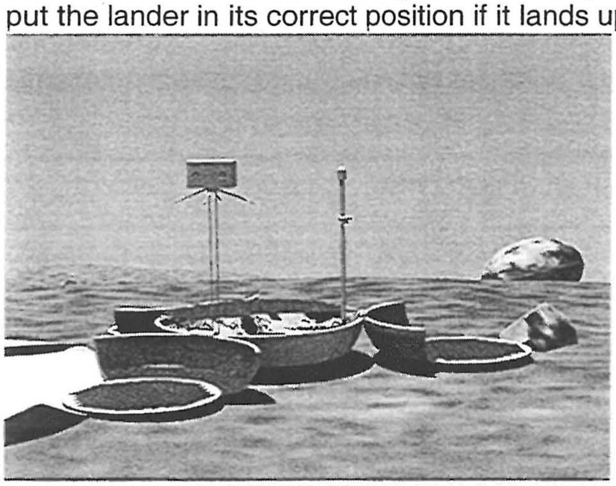
Each NetLander probe comprises two main sub-assemblies:
- the Surface Module,
- the Entry, Descent and Landing System (EDLS).

The EDLS function is to protect the Surface Module during all mission phases until its deployment on the surface of Mars. The atmospheric phase begins when the atmosphere is detected by accelerometer sensors. During the entry phase, the heat-shield reduces the velocity of the probe and the parachute system is activated when the probe velocity is low enough to allow parachute deployment. These conditions have to be obtained at high enough altitudes to maximise the efficiency of the parachute phase. Because of the low atmospheric density on Mars, the efficiency of the parachute system is limited: an additional landing system is necessary to reduce the landing shock.

After landing, the first operations will consist in the deployment of the solar arrays and the telecommunication antenna. The scientific instruments are then activated and checked. Before starting the network mode, first camera images will be acquired in order to characterize the landing site, and radar measurements will be performed.

The NetLander mission duration is expected to last over one Martian year.

During the surface operations, solar panels provide energy during day-time. Rechargeable batteries are used to store energy for night-time operations. In order to provide enough solar energy, deployable solar arrays are necessary: they are located on the internal surface of petals that are unfolded after landing. One of the petals also serves as a self-righting mechanism to put the lander in its correct position if it lands upside down.



NETLANDER in deployed configuration

The total mass of the NetLander probe is 66 kg when it enters the Martian atmosphere. After landing and ejection of all EDLS elements, the mass of the Surface Module is 22 kg, of which 5.2 kg are allowed for scientific instruments.

CHANGING THE MARS EDUCATION PARADIGM. D. J. Cowles and M. A. Trotter, Louisiana Nature Center Planetarium, PO Box 870610, New Orleans, LA 70187-0610, DCowles@auduboninstitute.org (corresponding author), MTrotter@auduboninstitute.org.

Introduction: The general public is fascinated by planetary exploration; witness the phenomenal response of the public to the *Mars Pathfinder* mission – almost 47 million hits on the mission's website in a single day. [1] Planetaria worldwide host over 63 million visitors each year, and almost 24 million of these planetarium visitors are in the United States—almost one person per eleven U. S. citizens. [2] The general public is definitely interested in planetary exploration and astronomy, but most mission outreach efforts are designed to serve only classroom teachers and students at the K-12 level. These education targets are well served, as any of the current mission websites will clearly show. Emphasis on teachers and K-12 students alone, however, neglects to educate the public at large. This gap can only be partially filled by planetaria; changing how mission planners and mission scientists approach education will help to further close this gap.

Mars missions can directly benefit from early planning of educational efforts. An aggressive education program will make the public better informed when making decisions about funding Mars missions, and will better inform them of the importance of continued planetary exploration.

Limitations of the Present System: There are several limitations to the present system of educating the public about planetary exploration. The most obvious limitation is the lack of emphasis on the general public. This is surprising since the public ultimately funds planetary exploration. Websites can partially ameliorate the problem by giving direct access to information about scientific missions, but not all websites are equally well-designed (the *Mars Pathfinder* site is considered by web professionals to be an excellent example of what a mission site should be [3]). Also, many people do not have Internet access at home, and little access if any in their local community.

Many planetaria are facilities that serve the general public but they, too, are limited. There are currently only 2504 planetaria worldwide. [2] Given the cost of building and equipping such facilities, it is not likely that this number will increase rapidly in the near future. Planetaria that serve the general public (as opposed to school planetaria) tend to be clustered in urban areas. Even though most of the US population is urban, a sizable fraction of the US population is rural and not in close proximity to a planetarium.

Some planetarians in public-access facilities see themselves as primarily concerned with basic visual astronomy and not planetary exploration. Those that do include planetary science as part of their teaching program may not have access to the most current information. Pre-recorded planetarium shows are difficult to change once they are produced, and these programs are not always replaced in a timely fashion, due to time constraints as well as budgetary considerations. Some planetaria don't offer live programs at all, relying entirely on pre-recorded programs, which limits the accuracy of the information contained in a particular show to the accuracy present at the time when the show was written.

Discussion: Since the general public has a strong interest in space and planetary exploration, everyone concerned with education should make efforts to capitalize on that interest, including those who are directly involved with planetary missions. The normal educational programs that NASA missions support are not geared to reach the public at large. Here are some methods to correct the gap in public education: educating the planetarium community to improve show quality, and working with local libraries and planetaria to give public presentations about Mars and missions to Mars.

Educating Planetarians: The planetarium community comes from a wide variety of educational backgrounds. Most hold degrees in education, communication, or a science or engineering degree, but not all of them do. Most have experience in amateur astronomy.

As a general rule, planetarians know far more about the space program and about planetary exploration than the general public or science teachers. Planetarians' knowledge is limited, however, by the lack of direct access to the planetary science community. A planetarian's knowledge can only be as current as the knowledge that is generally available. Most planetarians do not read the professional science journals because they do not have the background needed to understand the content. Planetarians are, however, a major source of information for the general public on matters concerning planetary exploration. Thus there is a gap between what planetarians know and what they need to know to be effective communicators and educators about planetary exploration. Closer ties between the planetary science and planetarium communities can eliminate this gap. The public would benefit from this collaboration because the information content of planetarium programs would be more accurate, and the public would be better informed when making decisions about funding missions to Mars. The planetarium community would benefit through better access to accurate information about Mars exploration. The planetary science community would benefit from access to a network of educators who specialize in science education.

Educating the Public: The planetary science community can directly reach out to educate the public through public lectures and presentations. Many planetaria offer live public programs, and most would be willing to host a planetary scientist to discuss his or her work. Public libraries normally offer public lectures at the adult and young adult level, and would appreciate the opportunity to have a planetary scientist speak. Some libraries may offer to host a scientist on a regular basis; one of the authors (Cowles) regularly presents astronomy programs at local libraries, averaging six to eight programs a year. Communicating directly with the public would allow members of the planetary science community to personally explain the significance of their work to the public, to gauge public interest in Mars exploration firsthand, and to help generate media attention for Mars missions.

Recommendations: Education efforts should not just be limited to teachers and to students at the K-12 levels. To reach the general public will require a broader base of educational initiatives than are currently available. These new initiatives should involve both the planetary science community and the planetarium community. These initiatives should begin while missions are still in the process of being defined.

A first step would be for planetary scientists and planetarium professionals to meet in a open forum to discuss ways to improve communication between the two groups, and to establish regular communication pathways between them. A series of workshops to educate planetarians about planetary science and to educate scientists on effective methods to teach the general public would be a good way to establish lasting contacts. The planetary science community would gain direct access to a group with specialized skills in presenting information to the public, and the planetarium community would gain access to the group that actively researches the planets and who can provide accurate, up-to-date information.

A second step would be for the planetary scientists to communicate directly with the public about their work. They are the most knowledgeable source of information about their work, for obvious reasons, and they are in the best position to help generate public enthusiasm about planetary exploration. Planetaria and public libraries are two possible venues for direct contact between the planetary science community and the general public. Lectures in a public forum such as a library or a planetarium can be a draw for the media, further enhancing public visibility of Mars missions and helping to further public education efforts.

Early planning for education programs will benefit Mars missions. The public will be better–informed about efforts to understand Mars, why these efforts are important, and—most importantly—why they should continue to receive funding.

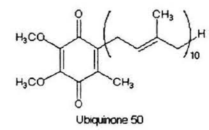
References: [1] Kirkham G. R. (1997) Asahi Award acceptance address in Tokyo, October 8, 1997 (Text at http://mars.jpl.nasa.gov/MPF/awards/asahi.html). [2] Petersen, M. C. (2000) Tallying the World's Planetarium Attendance. January 22, 2000. Posted at http://www.lochness.com/pltref/attend.html. [3] Toporek C. (1997) Webmastering Mars. *Web Review* (Internet magazine). July 18, 1997 issue. http://webreview.com/97/07/18/feature/index3.html

DESCRIBING AND MEASURING THE CHEMICAL SIGNATURES OF LIFE. R. L. Crawford[1], A. Paszczynski[1], Q. Lang[2], I. F. Cheng[2], B. Barnes[2], T. J. Anderson[2], R. Wells[2], C. Wai[2], G. Corti[2], L. Allenbach[2], D. Erwin[2], J. Park[2], and M. Mojarradi[3], [1]Environmental Biotechnology Institute, University of Idaho, Moscow ID 83844-1052 (crawford@uidaho.edu); [2]University of Idaho, Moscow ID 83844; and [3]NASA Jet Propulsion Laboratory, Pasadena, CA.

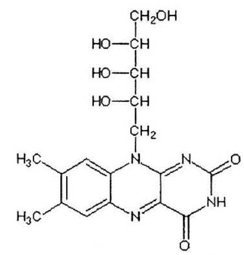
Introduction: Here we discuss an approach to remotely detecting extraterrestrial life forms on other planets or their moons by detection of specific types of organic molecules. The life entities to be detected would be presently active life forms, or those that are only recently dormant. The only place beside Earth's moon where humans have actually examined surface soils for the presence of organic molecules is Mars. This was accomplished using mass-spectrometry during the Viking mission, and results were negative. The lack of organic moieties, if they ever were present, probably resulted form their destruction over geologic time frames by the extraordinarily reactive surface soils found there. Thus, on Mars detection of organic signatures of life probably would be possible only in subsurface soils, or perhaps in polar regions.

Approach: In developing an approach to detection of life, we attempt to be non-Earth-centered in our thinking, recognizing, however, that Earth's life forms also must be detected by any life-detection system. The proposed approach is based on the several fundamental thermodynamic assumptions. Life, defined as the ability for self-replication, requires a continual input of energy. This energy must be tapped in a controlled (step-wise) manner. Further, as we understand these processes on Earth and apply them universally, energy is tapped via step-wise electron transport between electron donors and acceptors along an electron transport chain. Thus, we should be able to detect the core chemical components of such electron transport chains as a signature of life. On Earth such core structures are principally molecules resembling the porphyrins, quinones, flavins, and nicotinamides, as seen in photosynthetic pigments, redox enzymes, and cytochromes in earthly life forms (Figure 1).

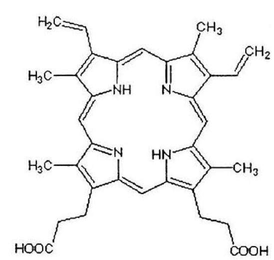
Figure 1. Model signature redox molecules.



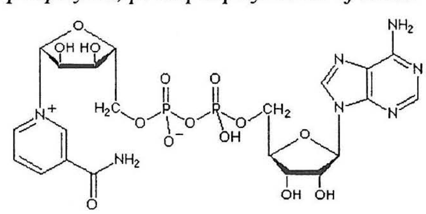
A model quinone, represented by ubiquinone



A model flavin, represented by riboflavin



A model porphyrin, protoporphyrin IX of heme



A model of diphosphopyridine nucleotide represented by nicotinamide-adenine dinucleotide (NAD)

Similar redox-active molecules might support life processes in extraterrestrial locations, though the actual molecular structures could be variations of or even different from those seen on Earth. For validating this redox signature based approach, biological samples from Earth were used for proving detection methods that might ultimately be miniaturized and used remotely and robotically in extraterrestrial locations. Signature chemicals were extracted from soil (with or without added bacterial cells) and analyzed in a multistep procedure using equipment that can be developed in the form of an integrated "laboratory on a chip." Soil was extracted in an extraction module that employed a variety of solvents (aqueous or organic, or mixtures of these, or supercritical carbon dioxide with organic modifiers). Components of these extracts were separated in another module (a liquid chromatography or capillary electrophoresis system; Figure 2) and then analyzed in a detection module for characterizing any targeted signature chemicals present.

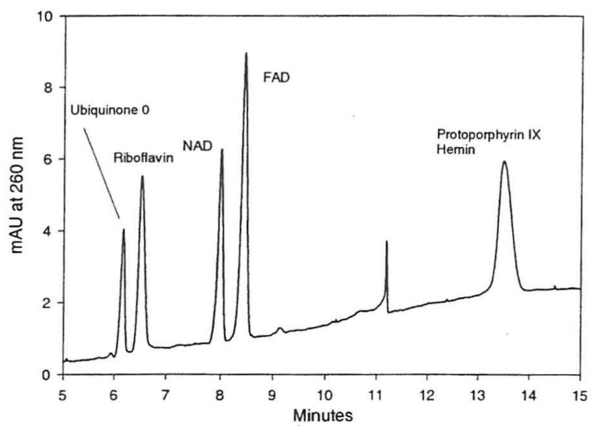


Figure 2. MECC electrophoresis separation of standards of signature redox molecules.

This module included an electrochemical detector and an electrospray mass-spectrometer. On earth we recognize that soils that contain life forms also should contain DNA. We used this property as a control in our validation experiments with Earthly samples. This was confirmed by DNA extraction and analysis by fluorometric techniques. Overall, we suggest that a successful life detection system based on a sequence of solvent extraction of signature redox compounds and separation of extracted components by capillary electrophoresis followed by voltametric and electrospray mass-spectroscopic analyses of specific signature chemical peaks indicating presence of an electron transport chain should perform well as an indicator of the presence of life in earthly or extraterrestrial samples (Figure 3).

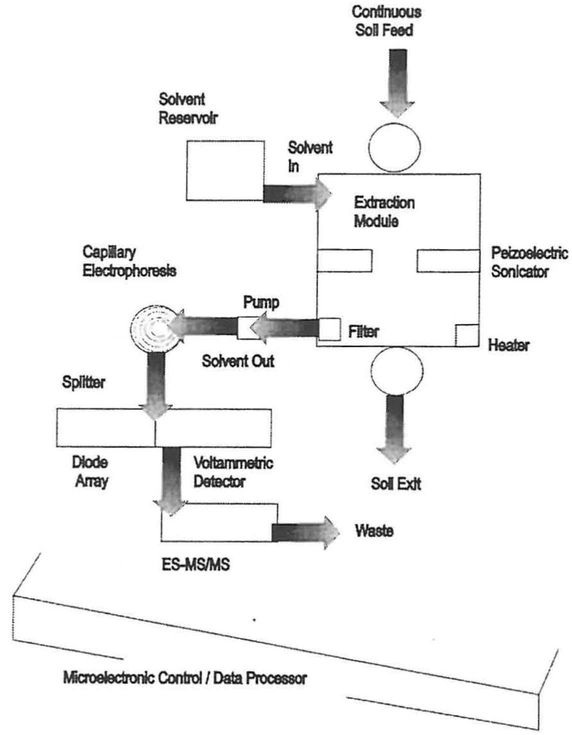


Figure 3. Possible lab on a chip design

Acknowledgement: Our work is being supported by award 1212404 of the NASA-JPL program, Grand Challenges: Chemical Signatures of Life.

IN-SITU ENVIRONMENTAL MEASUREMENTS NEEDED FOR FUTURE MARS MISSIONS. D. Crisp[1], G. R. Wilson[1], J. R. Murphy[2], D. Banfield[3], J. R. Barnes[4], W. M. Farrell[5], R. M. Haberle[6], J. Magalhaes[6], D. A Paige[7], J. E. Tillman[8] [1]Jet Propulsion Laboratory, California Institute of Technology, MS 180-404, 4800 Oak Grove Drive, Pasadena, California, 91109 (David.Crisp@jpl.nasa.gov, Gregory.R.Wilson@jpl.nasa.gov) [2]New Mexico State University (murphy@nmsu.edu) [3]Cornell University (banfield@astrosun.tn.cornell.edu) [4]Oregon State University (barnes@oce.orst.edu) [5]NASA Goddard Space Flight Center (farrell@faltraz.gsfc.nasa.gov) [6]NASA Ames Research Center (bhaberle@mail.arc.nasa.gov) [7]University of California, Los Angeles (dap@mvacs.ucla.edu) [8]University of Washington (mars@atmos.washington.edu)

Introduction: Existing measurements and modeling studies indicate that the climate and general circulation of the thin, predominately CO_2 Martian atmosphere are characterized by large-amplitude variations with a wide range of spatial and temporal scales. Remote sensing observations from Earth-based telescopes and the Mariner 9, Viking, Phobos, and Mars Global Surveyor (MGS) orbiters show that the prevailing climate includes large-scale seasonal variations in surface and atmospheric temperatures (140 to 300 K), dust optical depth (0.15 to 1), and water vapor (10 to 100 precipitable microns). These observations also provided the first evidence for episodic regional and global dust storms that produce even larger perturbations in the atmospheric thermal structure and general circulation.

In-situ measurements by the Viking and Mars Pathfinder Landers reinforced these conclusions, documenting changes in the atmospheric pressure on diurnal (5%) and seasonal (>20%) time scales, as well as large diurnal variations in the near-surface temperature (40 to 70 K), wind velocity (0 to 35 m/s), and dust optical depth (0.3 to 6). These in-situ measurements also reveal phenomena with temporal and spatial scales that cannot be resolved from orbit, including rapid changes in near-surface temperatures ($\pm$ 10 K in 10 seconds), large near-surface vertical temperature gradients ($\pm$15 K/meter), diurnally-varying slope winds, and dust devils (Figure 1). Modeling studies indicate that these changes are forced primarily by diurnal and seasonal variations in solar insolation, but they also include contributions from atmospheric thermal tides, baroclinic waves (fronts), Kelvin waves, slope winds, and monsoonal flows from the polar caps.

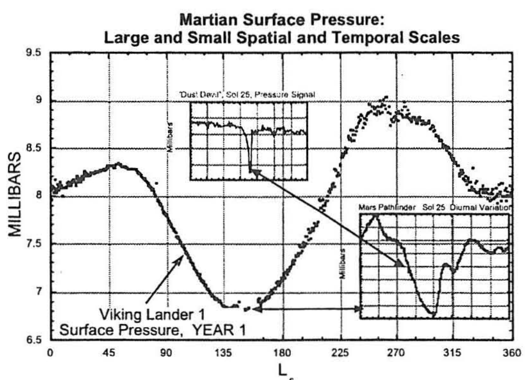


Figure 1. Seasonal, diurnal, and sub-hourly variations of pressure. The 20% seasonal cycle is driven by the sublimation of southern and northern polar caps respectively. The diurnal variation is due to day-night temperature difference. Sub-hourly variations are caused by transient events, such as dust devils.

Measurements Needed: In spite of these advances, additional measurements are needed to fully characterize the Martian atmosphere. In-situ measurements from networks of surface weather stations are needed to monitor the near-surface thermal structure because remote sensing measurements do not provide the spatial and temporal resolution needed to resolve the large gradients that characterized this environment. Other parameters, including the surface pressure, wind velocities, airborne dust and ice abundance, and electric fields cannot be reliably measured from orbit.

Long-duration measurements of atmospheric pressures are needed to monitor the seasonal pressure cycle, as well a broad range of phenomena on both large scales (dust storms, fronts, tides) and small scales (dust devils). A more complete description of the atmospheric thermal structure and dynamics is needed for studies of the processes that control the exchange of heat, mass, and momentum between the surface and the atmosphere, because these processes play an important role in the climate and general circulation.

Improved constraints on the properties of the Martian planetary boundary layer are also needed because this will be the working environment for future landers, rovers, and manned missions to Mars. For example, radiatively driven 60 to100 K temperature variations, combined with convective heat transport by winds, place severe demands on the thermal design of landers and instruments. Solar power systems are affected by both airborne and settling dust. High winds can introduce vibrations that affect sensitive instruments (e.g. seismometers, high-resolution cameras), and can place increased demands on landing systems. Atmospheric electrical phenomena may compromise surface instruments and subsystems, and may prove hazardous to Mars ascent vehicles.

END-TO-END RISK ASSESMENT: FROM GENES AND PROTEIN TO ACCEPTABLE RADIATION RISKS FOR MARS EXPLORATION. Francis A. Cucinotta[1] and Walter Schimmerling[2]. [1]NASA, Johnson Space Center, Space Radiation Health Office, Houston TX 77058. Email: Fcucinotta@ems.jsc.nasa.gov, [2]NASA, Headquarters, Washington D.C, 20546

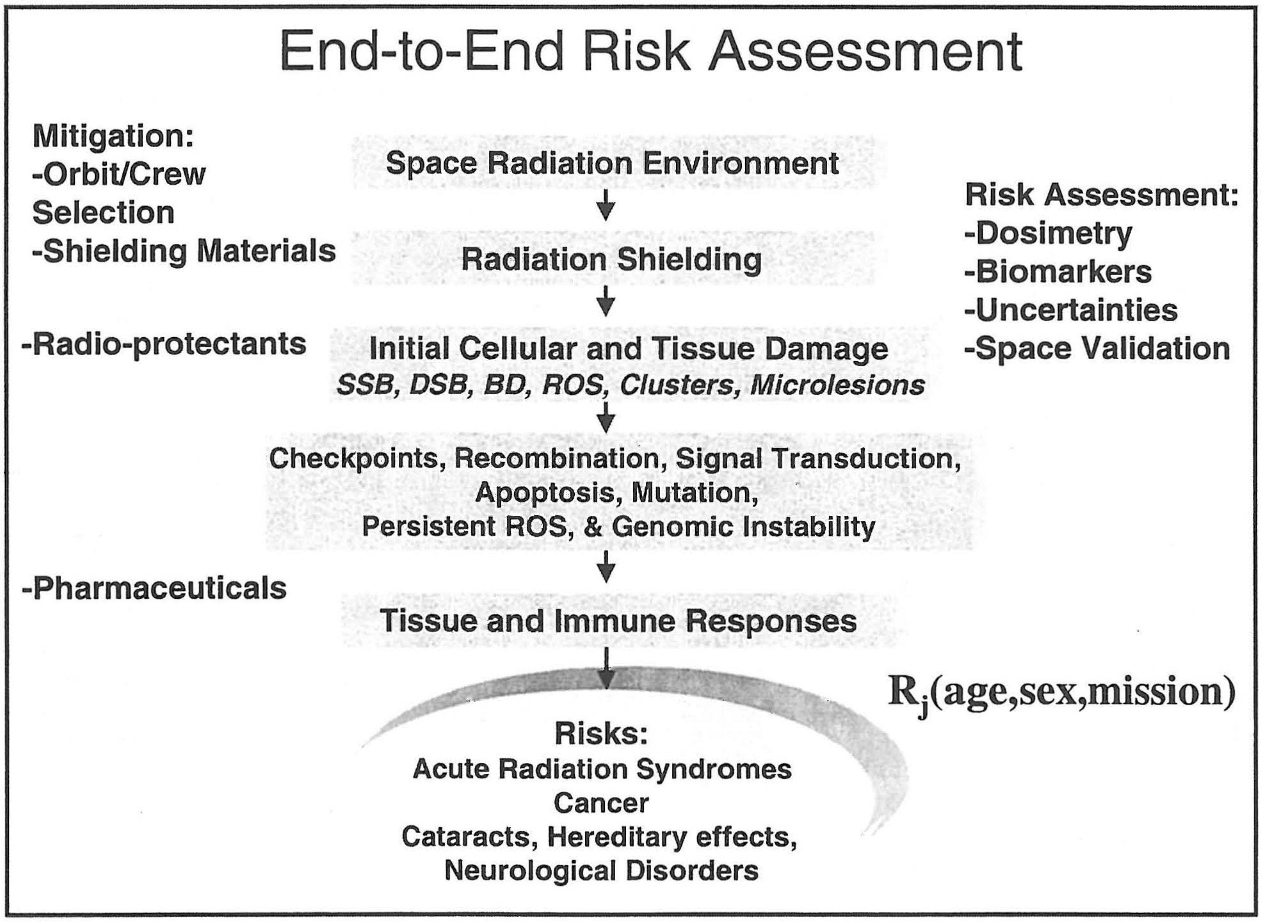
Introduction: The human exploration of Mars will impose unavoidable health risks from galactic cosmic rays (GCR) and possibly solar particle events (SPE). It is the goal of NASA's Space Radiation Health Program to develop the capability to predict health risks with significant accuracy to ensure that risks are well below acceptable levels and to allow for mitigation approaches to be effective at reasonable costs. End-to-End risk assessment is the approach being followed to understand proton and heavy ion damage at the molecular, cellular, and tissue levels in order to predict the probability of the major health risk including cancer, neurological disorders, hereditary effects, cataracts, and acute radiation sickness and to develop countermeasures for mitigating risks.

End-to-End Risk Assessment: Figure 1 describes the End-to-End approach for risk assessment for Mars exploration. A major problem for risk assessment is the need for improved understanding and a radiobiology database to evaluate risks for late effects from heavy ions. The limited radiobiological data for heavy ions in cellular and animal models suggests that variables such as dose or dose equivalent are poor predictors of risk. Instead, new variables that relate properties of particle track structure at the biomolecular and tissue levels to important biological effects are needed. It is only through improved fundamental understanding of biological processes at the level of DNA damage, protein expression, signal transduction, and tissue responses can an accurate risk assessment model be developed.

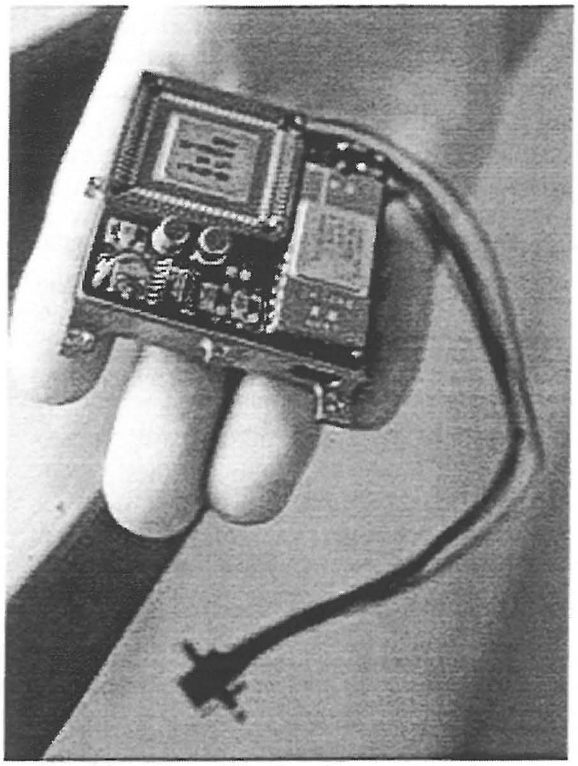
Mitigation or risks include operational decisions on the length of the mission, period in the solar cycle, crew age and sex, and possibly genetic sensitivity. Even today we known of genetic pre-dispositions in a significant fraction of the population including loss or inactivation of genes such as ATM, BCL, and BRCA that would place individuals at an enhanced risk for deficient DNA damage repair. Critical research in these areas will be performed at the NASA sponsored Booster Application Facility (BAF) at Brookhaven National Laboratories (BNL) beginning in 2003. NASA has made great progress in understanding the advantages of light mass materials for decreasing radiation exposure from GCR and SPE. Integration of this knowledge could be performed at BAF in order to develop shielding approaches for Mars transfer vehicles and surface habitats. However, realizing a design for exploration missions can not be made until crucial radiobiological research is performed. The final approach to risk mitigation is the development of biological countermeasures modulating the biological mechanisms of radiation response. Two approaches can be considered. The first involves the use of radioprotectants including anti-oxidants to decrease initial DNA damage and increase repair. For e.g., the use of targeted gene expression has been studied for promoting apoptosis of damaged cells, or prolong cell cycle arrests that allows more time for DNA damage processing to occur. The second approach involves the use of pharmaceuticals, vitamins, and other anti-oxidants to decrease persistent biological damage or counter-act early and intermediate-stage processes expected to be important in late effects such as cancer. Several drugs and vitamins are being considered; however they need to be shown effective for the low dose-rate exposures of protons and heavy ions characteristic of GCR and also unwanted side effects must be reduced or eliminated. Research in these areas can be performed with cell and animal models at BAF, and will be closely dependent on advances in our understanding of the underlying science.

Critical Path Roadmap: The critical path roadmap (CPR) for radiation health will establish the science and technology goals for implementing the End-to-End risk assessment approach. The CPR is based on past guidance received by NASA from the National Academy of Sciences and the National Council on Radiation Protection, and by the NASA Radiation Health Strategic Plan. The CPR includes defined milestones and deliverables in five programmatic areas (environments, shielding, dosimetry, crew risk factors, and risk assessment) and five research areas (cancer risks, central nervous system (CNS) risks, acute risks, synergistic effects of radiation and other space factors, and the development of biological countermeasures). (Available from the author). We will present an overview of the Radiation Health CPR in our paper.

Fig. 1. Roadmap for End-to-End Risk Assessment, an approach to achieve the goal of safe human exploration of space with acceptable risk from space radiation exposures.



AN ACOUSTIC SENSOR FOR THE NETLANDER MISSION G.T. Delory[1], J.G. Luhmann[1], F.S. Mozer[1], D.W. Curtis[1], L. D. Friedman[2], J.J. Berthelier[3] and P. Lognonne[4], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720, [2]The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, [3]Institut de Physique du Globe de Paris, 4 Avenue de Neptune 94100 Saint Maur des Fosses, France. [4]Institut de Physique du Globe de Paris, BP89 4, pl. Jussieu 75252 Paris cedex 05.



Introduction: We describe a microphone sensor currently under development by the University of California at Berkeley Space Sciences Laboratory for use on the CNES sponsored Netlander mission, based on the original Mars Microphone constructed for the Mars Polar Lander program. The Netlander mission, scheduled to land four identical probes on the surface of Mars in 2005, represents a unique opportunity to sample from multiple locations the acoustic signature of the meteorological environment as well as lander generated sounds which may be of both engineering and scientific significance. The microphone will be part of an integrated suite of sensors, including a seismometer, infrasound detector, and an electric field sensor, forming a comprehensive measurement system for the acoustic and electric properties of the atmosphere during storm activity as well as quiet periods. Currently selected for a phase B design study, the Netlander microphone development effort will focus on a smaller, lighter weight version of the instrument flown on MPL. This instrument is sponsored by The Planetary Society, and is expected to add a significant contribution to the educational and public outreach capabilities of the Netlander instrument package.

Science Background and Objectives: The basic properties of acoustic signals on Mars have been investigated recently by several groups, who were in part motivated by the presence of Mars Microphone on MPL. Given the recent MPL failure combined with a complete lack of direct acoustic measurements on previous missions these results depend heavily upon basic atmospheric conditions measured by the Viking landers and the Mars Pathfinder mission. On Mars the typical surface pressure is 5-10 millibars, the average temperature ~210 K, the atmospheric mass density is ~1.4% the terrestrial value, and the sound speed is roughly 230 m/sec compared to 360 m/sec on Earth. Under these conditions Sparrow [1] showed that the sound intensities are only reduced by 20 dB, or a factor of 10 in amplitude, compared to the same source in the terrestrial environment. Frequency shifting effects may also be present on Mars, with the resonant Helmholtz frequency ~0.66 of the value in Earth's atmosphere. Beyond these simple affects, more detailed calculations by Williams [2] has shown that attenuation of higher frequency sounds is much greater on Mars than on Earth. By considering molecular, thermal, and viscous relaxation effects in the Martian atmosphere, a sound wave with a 50 dB source intensity may propagate only a few meters before being reduced to less than 0 dB in power, below the detection threshold for the average human ear. Thus distant sound sources may appear to emit spectra weighted towards the lower frequencies, with the higher frequencies becoming detectable as the source moves closer.

An acoustic sensor on a planetary lander is likely to record a mixture of natural and artificial sounds. Naturally occurring sounds will almost certainly result from weather driven processes, caused by the wind, sandstorms, or dust devils, and the interaction of these phenomena with the lander structure. A microphone on the Russian *Venera* Grozo 2 instrument was able to measure the wind speeds on the surface of Venus by using calibration data from wind tunnel tests as well as supporting measurements from other instruments on the mission [3]. In the case of the more violent events on Mars such as dust devils and sandstorms, we can use terrestrial analogs as a guide to their acoustic signature. Terrestrial tornados emit noise in the kHz range within a few hundred meters and the same may be true of Martian dust devils [4]. The Mars Pathfinder panoramic camera imaged at least five dust devils that moved with velocities between 0.5-5 m/sec which carried sufficient quantities of dust to reduce the lander solar cell efficiency by as much as 1% [5]. Thus future landers may be likely to encounter these violent wind vortices at sufficient proximities for useful acoustical measurements to be taken. In addition to producing a simple rush of atmosphere past the microphone, sandstorms and dust devils may be electrically active due to triboelectric charging effects, especially if the Martian dust carried in these storms has a wide range of particle sizes [6,7,8]. Electrical charging due to relative dust motion can result in a static glow discharge, which may emit sounds. Discrete electrical discharges are a regular result within volcanic dust plumes [9] and may also be present in sandstorms and dust devils on Mars, in which case the Mars Microphone could record Martian thunder.

Artificial sounds generated by the lander will also be of interest for both scientific and engineering considerations. The microphone can be used to record the deployments of instruments after landing, as well as to troubleshoot and verify critical events during entry, descent, and landing that may generate noise. The tones of camera or other electric motors during the mission can be recorded and compared to identical tests under Terrestrial conditions; subsequent FFTs of this data may verify the predicted high frequency attenuation and frequency shifting effects for sounds generated in the atmosphere of Mars.

Educational Outreach Objectives: The significant public interest generated by the inclusion of Mars Microphone on the MPL mission underscored the potential for public outreach and education on missions that endeavor to bring the public closer in every way possible to the experience of planetary exploration. The MPL microphone generated radio and essay contests among students and adults, as well as significant press coverage on radio, television, and the internet worldwide. In the case of a future microphone on Netlander, it is planned to leverage this now well-established public enthusiasm for an extra-terrestrial microphone in order to create a significant amount of educational outreach for the mission. The Planetary Society, with significant experience in the process of involving and exciting the public in planetary exploration, will accomplish this through its worldwide membership activities as well as through partnerships with organizations such as Disney and educational web content providers.

Technology Development: The original microphone developed for the MPL mission was driven by very low cost, power, and telemetry bandwidth constraints. Consisting of a small circuit board 2.5 cm square, it had a mass of 50g, used less than 100 mW of power, and yielded 2.5 to 10 second long snapshots of sound sampled at rates of up to 20 kHz requiring ~24 kilobytes of data. The microphone used was an electret type with a frequency response between 100 Hz and 10 kHz and a lower sensitivity of ~3 dB. A sound processor chip consolidated A/D sampling, digital filtering, sound compression, and data I/O on one IC. Non-volatile memory stored several 10-second sound clips in-between power cycles; the device was rad tolerant to 10 kRADs and could operate between temperatures of –80 to +50 degrees C.

The next generation microphone for use on Netlander faces different yet equally challenging design considerations. The severe mass limitations for Netlander instruments require a lighter microphone system, no more than 25g in mass. Unlike the sunlit MPL landing site in the high southern latitudes, a Netlander-based sensor will likely have to withstand a wider temperature range of –120 to +50 C. Both of these design constraints can be mitigated through the use of hybrid circuits, producing a smaller, more temperature tolerant device. Additional mass savings may be accomplished through consolidating some of the microphone sampling electronics with similar circuits in the electric field experiment. It is also desired to increase the data rate of the device, which is easily accommodated by the availability of higher density memory chips since the MPL design effort, resulting in ~10 times the sound storage capability of the original Mars Microphone, enabling up to several minutes of 5 kHz sampled sound per day or more, depending upon the telemetry allocation given to the instrument.

References: [1] Sparrow, V. W., (1999), *J. Acoustic. Soc. Am.*, 106, 2264. [2] Williams, J-P., (1999) The acoustic environment of the Martian surface, submitted to *JGR*., Dec 1999. [3] Ksanfomaliti, L.V. et al. (1983), *Kosmicheskie Issledovaniya*, Vol 21., No. 2, pp. 218-224. [4] Arnold, R.T. et al., (1976) *J. Acoustic. Soc. Am.,* 60, 584. [5] Metzger et al., (1999) JGR. [6] Eden, H.F., and B. Vonnegut, (1973), Science 180, 962. [7] Kamra, A.K., (1972) *JGR*., 77, 5856. [8] Eden, H.F., (1977) Electrical Processes in Atmospheres, ed. by H. Dolezalek, R. Reiter, Springer Verlag. [9] Farrell, W.M. et al., (1999) *JGR*, 104, 3795.

EXPLORATION STRATEGIES FOR HUMAN MISSIONS: MARS FIELD GEOLOGY, BIOLOGY AND PALEONTOLOGY WORKSHOP. Patricia Wood Dickerson, Lockheed Martin, NASA - Johnson Space Center, C 23, Houston, TX 77058. pdickers@ems.jsc.nasa.gov.

Introduction: Field exploration strategy, crew skills and training, analytical capabilities, and Earth-Mars communications were themes of the Mars Field Geology, Biology and Paleontology workshop [1] convened by Michael B. Duke, David S. McKay, and William R. Muehlberger (November, 1998). The intent was to expand the exploration culture within NASA: one which captures the experience and insight of the scientists, mission operations personnel, and crews of the Apollo and Skylab explorations; one which applies and develops new technology appropriate to the quest; one which clearly articulates the scientific questions and scrupulously reports both data and interpretation.

The convenors charged the thirty-one veteran field scientists and space explorers to frame specific recommendations, which would build upon mission architecture developed for human exploration of Mars [2, 3] and which would be incorporated in science requirements for future NASA missions.

Field Exploration Strategy: A human mission provides an unprecedented opportunity to use the immense power of the explorer's mind to comprehend Martian processes and history in extraordinary detail. In contrast with lunar exploration, many or most sites on Mars will have been reconnoitered robotically and samples analyzed before humans arrive, providing a reasonable assessment of landing sites before people ever step onto the surface.

Recommendations. 1) While acclimating to Martian gravity, the crew should initiate robotic reconnaissance of biohazards, terrain, local geology, potential resources. 2) Safety protocols and contingency plans should be in place and drills conducted prior to any EVA. 3) Only two to three of the six astronauts should be on an EVA at any time, so that if necessary, crew members remaining at Mars base could rescue them. 4) Traverses should be designed with considerable flexibility in time and tasks; workloads must be carefully considered. 5) Traverses should be designed with increasing complexity as skill and confidence increase. 6) Initial walking traverses should be to the highest priority sites identified. 7) When one-day walking traverses from base are complete, the Earth and Mars science teams should spend one or two days synthesizing results and designing extended traverses. 8) Geophysical studies of the landing site should begin early to determine if water or other resources might be present at accessible depths. 9) Advances in Mars suit and glove functionality are imperative — especially in glove flexibility, dexterity, and performance. 10) A new reach-and-grasp tool must be developed for collecting samples in the 10- to 30-cm size range.

Analytical Capabilities & Instruments: Robotic reconnaissance of the Martian surface, human field explorations, and preliminary laboratory research will focus both on fundamental scientific questions and on site and resource assessment. Both endeavors will require observations, measurements, sampling, and analysis of Martian material, and geophysical studies. The team framed their recommendations of candidate instruments in terms of six specific objectives in the human exploration of Mars: field observation, sample acquisition, maintenance of crew health and safety, search for evidence of past or present life, geological and geophysical field investigation, sample selection and preparation.

Recommendations. 1) The need for specific observations and analyses should be the primary driver for the development of compact, integrated field instruments. 2) Miniaturization of existing instruments and the design of ones for field exploration and laboratory work on Mars should begin now – for example: a) Helmet-mounted fiber-optic camera, b) Magnifying camera that could also serve as hand lens, c) Electronic field notebook, d) Voice-activated data recording system with real-time data display on viewing panel inside visor, e) In-visor map to locate (x, y, z) samples and outcrops, f) Bar-coded sample bags and containers that can be registered using a digital modification of the hand-lens. 3) Biologists, field geologists, geochemists, and engineers should collaborate throughout mission planning to develop multipurpose instruments.

Crew Skills and Training: Satellite imaging, robotic reconnaissance, sample examination, and base-map construction will precede human investigation of any site. Because crew members will have opportunities to make notable contributions to our understanding of the planet, all should be fully grounded in martian geology and planetary science before flight.

Recommendations. 1) The expedition crew should have roughly twice as many members with primary surface science skills over those with backgrounds in spacecraft systems and operations. 2) Mars crew training should culminate in an extensive program of realistic field exploration simulations. Crew, operations, and science support teams should participate in at least six field exercises before launch. 3) In 1999 NASA should begin a field training program for astronauts, mission operations, and science support teams, aimed at gaining experience in surface science operations. 4) NASA should convene additional workshops on: a) Crew selection, including crew skills, other pertinent criteria; b) site selection for field science exercises; c) recording the collective experience of Apollo and Skylab crews, science support teams, and missions operations personnel. 5) NASA should sponsor an expert workshop to thoroughly investigate the gender and nationality mix best suited for Mars mission success.

Earth-Mars Communications: Apollo investigations taught us valuable lessons, not only in setting strategy and in data and sample collection, but also in assuring effective dialogues between the explorers and scientists on Earth. Communications technology has evolved dramatically since the Apollo era and will evolve further before the first human mission to Mars. Participants discussed the desired level of autonomy of crew members on Mars, the principal objectives for communication between astronauts on Mars and scientists on Earth, accommodation of the forty-minute time lag, and how to effect real-time changes in exploration strategy.

Recommendations. 1) The mission communications network should include: a) satellites in Mars orbit for communications and navigation during surface exploration, b) dependable communications with Earth and any existing orbiting outposts, c) voice- or touch-activated instruments for recording and reporting exploration activities and displaying data; fail-safe back-up, d) capability for data compression and transmission of large volumes of data, particularly from geophysical surveys. 2) Plans should accommodate more structured communication during early reconnaissance stages and less structured communication with Earth in later stages of the mission. 3) The capability for teleoperation of field or laboratory analytical equipment and robotic rovers from Mars base, or from Earth, should be developed. 4) Communications among scientists on the two planets should take place at several well-defined levels: a) Astronaut scientists and science teams ("science back room") on Earth should be in regular contact throughout the mission. A crew member at Mars base would serve as point-of-contact when other members are on EVA. b) Science teams on Earth would change, as dictated by progress in exploration and the kinds of analytical data being returned. Various specialists would be on call in the event of discoveries or anomalies. 5) Briefing and debriefing should occur between arriving and departing crews, as permitted by the relative locations of spacecraft in transit. 6) To keep the public engaged in the quest, mission news (science questions, crew selection, training, etc.) should be reported promptly and accurately. Scientific discoveries/results should be directly translated into teaching materials for students at varying levels.

Progress: Recommendations from this workshop are being transformed into mission preparations. Field geophysical training for astronaut candidates began in summer, 1999 [4], and an astronaut will participate in the 2001 Antarctic meteorite expedition. A dedicated console has been established in Mission Control at JSC to support field exploration simulations. Project proposals are in review for scientific and engineering assessments of terrestrial analogues to Martian sites. A workshop on Apollo exploration strategies and experience will soon be convened. Thus, substantive steps are being taken toward revitalizing a culture that is prepared for the risks and the rewards, the elation and the responsibilities of human exploration of other worlds.

References:

[1] Budden N. A. (1999) LPI Contribution 968. [2] Hoffman S. J. (1997) NASA SP 6107. [3] Drake B. G. (1998) NASA EX13-98-036. [4] Dickerson P. W. and Muehlberger W. R. (2000) this volume.

ON THE GROUND: ASTRONAUT TRAINING FOR PLANETARY EXPLORATION. Patricia Wood Dickerson[1] and William R. Muehlberger[2], [1]Lockheed Martin, NASA - Johnson Space Center, C 23, Houston, TX 77058, pdickers@ems.jsc.nasa.gov. [2]Department of Geological Sciences, University of Texas, Austin, TX 78712, wmuehl@ mail.utexas.edu.

Scientific questions about martian origins and evolution will be addressed and resources assessed through both human and robotic exploration — essential and complementary strategies. Satellite imaging, robotic reconnaissance, sample examination, and base-map construction will precede the arrival of humans at any exploration site.

Field exploration is learned in the field. Geological field surveys, petrological/ geochemical laboratory experience, polar geology and other polar field programs, oceanographic voyages, paleobiological field programs, scientific drilling projects, volcanological field work, and eventually, multiweek stays aboard the Space Station or at a lunar outpost could all provide needed experience. All would combine real scientific work for the crew with realistic support from an integrated ground team.

Beginning with the Apollo program, astronaut training has included geological field instruction in northern New Mexico. Field observations and discussions are reinforced by means of photographs taken by astronauts of Earth and the Moon, to provide an orbital perspective. Participants are exposed to excellent examples of geological features that illustrate not only terrestrial concepts and processes, but also analogous ones on other planetary bodies.

Mars analogues include ancient and modern sand dune fields, river-cut canyons, groundwater sapping features, and volcanoes of all sizes with lavas of various chemical compositions. Lunar analogues include basaltic lava plains and a one-to-one scale model of Hadley Rille, the Apollo 15 landing site. In addition, the region furnishes examples of active faults, glacially cut valleys, marine fossils (now at elevations more than 8,000 feet above sea level), a major rift valley and its internal complications, and continental to marine sedimentary sequences.

In 1999 NASA began field training in surface science operations. To initiate instruction in geophysical methods appropriate for planetary exploration, a field geophysical exercise was launched. Astronaut teams acquired roughly 16 km of gravity data in the course of a planetary exploration simulation conducted in northern New Mexico. The gravimetric survey was the first

Figure 1. John Young, lunar field explorer (with gravimeter), and James Reilly, geologist astronaut (right), assess the relevance of the simulation. Bill Muehlberger (center) instructs as Duane Ross, Leo Eyharts, and Lee Archambault (left to right) observe.

phase of a geophysical assessment of the groundwater resources around Taos, an arid region of rapid population growth; it was executed to help delineate buried structures that influence groundwater flow and accumulation in the valley.

The known geology and hydrology of the site and the probable magnitude of the buried faults suggested that gravity surveying, a technique attempted on the Moon, would provide needed data on the large buried structures. The contrast in density between bedrock (Precambrian metamorphic rock and massive Carboniferous limestone) versus unconsolidated valley sediment would permit definition of faults that juxtapose the two. Gravity surveying is passive — that is, no energy must be put into the ground in order to acquire data, and the small portable instruments permitted walking traverses. Both are critical considerations in planetary field exploration.

Each field crew was briefed on the geologic setting, on the scientific objectives, and on gravimetric surveying. Then, in the field, the stations where gravity readings would be taken were located by means of laser rangefinder, newly flown aerial photographs, and detailed topographic maps. Field station locations and gravity-meter readings were radioed to "Mars base" and the data were processed in real time by geophysics graduate students from New Mexico Institute of Technology. The next morning, each crew viewed the profile that they had acquired, participated in its interpretation, saw the data entered on the Bureau map, and helped select the location for the next traverse.

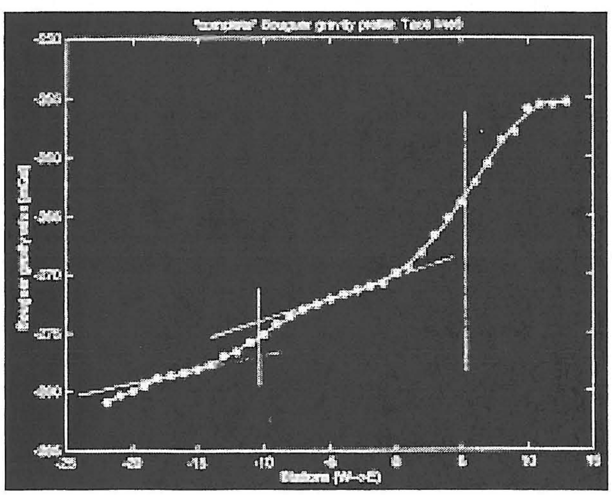


Figure 2. Complete Bouguer gravity profile acquired during the field exercise. The inflection at station 5 coincides with a major buried range-front fault that was delineated in the course of the exercise. That at station -10 marks the probable western edge of the fault block.

The 31 participants learned a technique with direct relevance for lunar and planetary exploration, from data acquisition through interpretation and planning of further work. They also took a substantive step toward revitalizing the exploration culture within and beyond NASA.

Martian Magmatic-driven Hydrothermal Sites: Potential Sources of Energy, Water, and Life. J.M. Dohm[1], V.R. Baker[1], R.C. Anderson[2], J.C. Ferris[1], T.M. Hare[3], K.L. Tanaka[3], J.E. Klemaszewski[4], D.H. Scott[5], and J.A. Skinner[3] [1]Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ, 85721, jmd@hwr.arizona.edu, [2]Jet Propulsion Laboratory, Pasadena, CA, [3]U.S. Geological Survey, Flagstaff, AZ, [4]Arizona State University, Tempe, AZ, [5]Private

Introduction: Magmatic-driven processes and impact events dominate the geologic record of Mars [e.g., 1-4]. Such recorded geologic activity coupled with significant evidence of past and present-day water/ice, above and below the martian surface, indicate that hydrothermal environments certainly existed in the past and may exist today. The identification of such environments [e.g., 5-25], especially long-lived magmatic-driven hydrothermal environments [e.g., 3, 26], provides NASA with significant target sites for future sample return missions, since they (1) could favor the development and sustenance of life, (2) may comprise a large variety of exotic mineral assemblages, and (3) could potentially contain water/ice reservoirs for future Mars-related human activities. If life developed on Mars, the fossil record would presumably be at its greatest concentration and diversity in environments where long-term energy sources and water coexisted [e.g., 8, 9, 10] such as at sites where long-lived, magmatic-driven hydrothermal activity occurred. These assertions are supported by terrestrial analogs. Small, single-celled creatures (prokaryotes) are vitally important in the evolution of the Earth; these prokaryotes are environmentally tough and tolerant of environmental extremes of pH, temperature, salinity, and anoxic conditions found around hydrothermal vents [27]. In addition, there is a great ability for bacteria to survive long periods of geologic time in extreme conditions, including high-temperature hydrogen sulfide and sulfur erupted from Mount St. Helens volcano [e.g., 27]. Our team of investigators is conducting a geological investigation using multiple mission-derived datasets (e.g., existing geologic map data, MOC imagery, MOLA, TES image data, geophysical data, etc.) to identify prime target sites of hydrothermal activity for future hydrological, mineralogical, and biological investigations. The identification of these sites will enhance the probability of success for future missions to Mars.

Preliminary Results: Preliminary work has revealed candidate sites of hydrothermal activity in the Tharsis region of the Western Hemisphere of Mars (**Table 1**). These sites are expressed through comparative analysis of geologic materials (e.g., map units) and features (sapping valleys and valley networks, fault and rift systems, erosional scarps, volcanoes, volcanic valleys and rilles, depressions such as pit crater chains, and fractures, canyons, hills, and mesas which are commonly associated with chaotic materials) and topographic (MOLA) and geophysical data (gravity and paleomagnetic) through time. We find that the Tharsis region is dominated by the formation of a long-lived magmatic complex comprised of numerous regional and local concentrations of tectonic activity interpreted to be magmatic domal uplifts often associated with volcanism and hydrothermal activity; these results are partly based on previous investigations [e.g., 25, 28, 29, 30].

Future Work: We will focus our attention on the candidate sites listed in Table 1 as well as continue our search for additional sites elsewhere on the Martian surface. Our primary objective is to select prime candidate sites from a large list of potential candidate sites for future mission planning (unmanned and manned missions); prime candidate sites are those sites that have the greatest potential to yield hydrological, mineralogical, and biological information. The selection of prime candidate sites will be based on identifiers, including: (1) morphologic feature types such as isolated valleys and valley networks (and other possible fluvial features), depressions including pit crater chains, erosional scarps, volcanoes, volcanic valleys and rilles, impact ejecta blankets that express volatile-rich target materials [e.g., 31, 32], and fractures, canyons, hills, and mesas which are commonly associated with chaotic materials [e.g., 33], (2) geophysical anomalies indicative of possible underlying intrusive bodies, (3) MOLA profiles, combined with other geological evidence, indicative of magmatic-related uplift and often associated volcanism, and (4) spectral signatures that may reflect ancient and modern ground water environments and ancient surface water environments. Prime candidate sites, for example, would contain the greatest percentage of the above identifiers.

Martian Magmatic-driven Hydrothermal: J.M.Dohm, V.R.Baker, R.C.Anderson, et al.

TABLE I. Candidate sites of magmatic-driven hydrothermal activity.

LOCATION (method; see Anderson et al., 1998 for explanation of vector and beta analyses)	**RELATIVE AGE (based from Dohm and Tanaka, USGS I-Map in press)**	**~ELEV. (m)**	**CITED WORK**
Claritas – 106°W, 27°S (vector analysis)	Stage 1 – Noachian	12,200	[30, 34, 35]
Syria Planum – 106°W, 14°S (beta analysis)	Similar to 1	14,500	[30, 34, 36]
Tempe – 81°W, 35°N (vector analysis)	Similar to 1	8,300	[37, 38]
Central Valles – 80°W, 16°S (vector analysis); 78°W, 12°S (beta analysis)	Stage 2 – Late Noachian to Early Hesperian	12,000	[30, 39, 40, 41, 42, 43, 44]
West Thaumasia Plateau – 111°W, 35°S (vector analysis)	Similar to 4	12,000	[1, 35]
Warrego - 95°W, 39°S (vector analysis and detailed rock-stratigraphic and structural mapping)	Similar to 4	11,500	[24, 25,29, 30, 37]
Southern Coprates (detailed rock-stratigraphic and structural mapping); near 62°W, 28°S	Similar to 4	10,800	[5, 6, 45]
Central Thaumasia Highlands (detailed rock-stratigraphic and structural mapping); near 88°W, 38°S	Similar to 4	12,000	[1, 25, 30]
Southwest Thaumasia Plateau; near 100°W, 41°S	Similar to 4	13,000	[1, 25, 30]
Northwest Syria Planum - 107°W, 4°S (vector analysis); 108°W, 3°S (beta analysis)	Stage 3 – Early Hesperian	13,500	[1, 46]
South Tempe - 82°W, 30°S (vector analysis); 80°W, 30°S (beta analysis)	Similar to 10	10,400	[37]
West Valles - 84°W, 5°S (vector analysis)	Similar to 10	10,000	[1, 39]
East Valles - near 49°W, 15°S (observation)	Stage 4 – Late Hesperian to Early Amazonian and possibly Stage 3	9,800	[1, 39]
Northeast Valles - near 61.5°W, 3°S (observation)	Similar to 13	9,000	
South Kasei - near 78°W, 3°N (observation)	Similar to 13	7,000	[37]
Alba Patera - 107°W, 37°N (vector analysis); 104°W, 42°N (beta analysis)	Stage 4 – Late Hesperian to Early Amazonian	12,000	[1, 15, 47]
West Kasei - 75°W, 25°N (vector analysis)	Similar to 16	7,500	
Southwest Arsia - 106°W, 7°N (vector and beta analyses)	Stage 5 – Amazonian	24,000	[1, 28, 46, 48, 49]
North Olympus Mons - 135°W, 28°N (beta analysis)	Similar to 18	6,000	[50]

References: [1] Scott, D.H., and K.L. Tanaka, 1986, U.S. Geol. Sur. I-Map 1802-A. [2] Greeley, Ronald, and Guest, 1987, U.S. Geol. Sur. I-Map 1802-B. [3] Dohm, J.M., et al., 2000, Lunar Planet. Sci., XXXI, 1613. [4] Baker, V.R., et al., 2000, Lunar Planet. Sci., XXXI, 1863. [5] Mouginis-Mark, P.J., et al., 1984, Earth, Moon, and Planets, 30, 149-173. [6] Mouginis-Mark, P.J., 1985, Icarus, 64, 265-284. [7] Mouginis-Mark, P.J., 1990, Icarus, 84, 362-373. [8] Mckay, C.P., and Stoker, C.R., 1989, Geophys. Space Phys., 27, 189-214. [9] Farmer, J.D., and Des Marais, D.J., 1997, LPI Contribution 96, 30-31. [10] Farmer, J.D., et al., 1997, LPI Contribution 96, 31. [11] Brakenridge, G.R., et al., 1985, Geology, 13, 859-862. [12] Newsom, H.E., 1980, Icarus, 44, 207-216. [13] Squyres, S.W., et al., 1987, Icarus, 70, 385-408. [14] Carr, M.H., 1979, J. Geohys. Res., 84, 2995-3007. [15] Gulick, V.C., and Baker, V.R., 1989, Nature, 341, 514-516. [16] Gulick, V.C., and Baker, V.R., 1990, J. Geophys. Res., 95, 14,325-14,344. [17] MacKinnon, D.J., and Tanaka, K.L., 1989, J. Geophys. Res., 94, 17,359-17,370. [18] Wilhelms, D.E., and Baldwin, R.J., 1989, Proceedings: Cambridge University Press and Lunar and Planetary Institute, 355-365. [19] Clifford, S.M., 1993, J. Geophys. Res., 98, 10,973-11,016. [20] Tanaka, K.L., and Clifford, S.M., 1993, LPI Tech. Rep., 93-04, Part 1, 17-18. [21] Squyres, S. W, and Kasting, J. F., 1994, Science, 265, 744-749. [22] Scott, D.H., et al., 1995, U.S. Geol. Sur. I-Map 2461. [23] Carr, M. H., 1995, J. Geophys. Res., 100, 7479-7507. [24] Gulick, V.C., et al., 1997, Icarus, 130, 68-86. [25] Tanaka, K:L., et al., 1998, J. Geophys. Res., 103, 31, 407-31, 419. [26] Wilson, L., and Head III, J.W., 1997, LPI Contribution 96, 85-87. [27] Nealson, K.H., 1999, Engineering & Science, California Institute of Technology, LXII, 31-40. [28] Anderson, R.C., et al., 1998, Lunar Planet. Sci., XXIX, 1881-1882. [29] Dohm, J.M., Anderson, R.C., and K.L. Tanaka, 1998, Astron. & Geophys., 39, 3, 3.20-3.22. [30] Dohm, J.M., and Tanaka, K.L., 1999, Planet. & Space Sci. 47, 411-431. [31] Barlow, N.G., and Bradley, T.L., 1990, Icarus, 87, 156-179. [32] Boyce, J.M., et al., 2000, Lunar Planet. Sci., XXXI, 1167. [33] Komatsu, G., et al., 2000, Lunar Planet. Sci., XXXI, 1434. [34] Tanaka, K.L., and P.A. Davis, 1988, J. Geophys. Res., 93, 14,893-14,917. [35] Craddock, R.A., and Maxwell, T.A., 1993, J. Geophys. Res., 98, 3453-3468. [36] Tanaka, K.L., Dohm, J.M., and Watters, T.R., 1996, Lunar Planet. Sci., XXVII, 1315-1316. [37] Scott, D.H., and Dohm, J.M., 1990b, Lunar Planet. Sci. Proc., XX, 503-513. [38] Scott, D.H., and Dohm, J.M., 1990a, in MEVTV Workshop "Evolution of Magma Bodies on Mars", 39-40. [39] Witbeck, N.E., Tanaka, K.L., and Scott, D.H., 1991, U.S. Geol. Sur. I-Map 2010. [40] McCauley, J.F., Carr, M.H., Cutts, J.A., Hartmann, W.K., Masursky, H., Milton, D.J., Sharp, R.P., and Wilhelms, D.E., 1972, Icarus, 17, 289-327. [41] Lucchitta, B.K., and Ferguson, H.M., 1983, Lunar Planet. Sci. 13, J. Geophys. Res. Suppl. 91:E166-E174. [42] Lucchitta, B.K., et al., 1992, Mars, H.H. Kieffer, B.M. Jakosky, C.W. Snyder, and M.S. Matthews(eds), University of Arizona Press., 147-183. [43] Tanaka, K.L., Golombek, M.P., and W.B. Banerdt, 1991, J. Geophys. Res., 96, 15,617-15,633. [44] McKenzie, D., and Nimmo, F., 1999, Nature, 397, 231-233. [45] Baker, V.R., 1982, Austin, University of Texas Press, 198. [46] Scott, D.H., et al., 1998, U.S. Geol. Sur. I-Map 2561. [47] Tanaka, K.L., 1990, Lunar Planet. Sci., XX, 515-523. [48] Tanaka, K.L., 1990, Lunar Planet. Sci., XX, 515-523. [49] Scott, D.H and Zimbelman, J.R., 1995, U.S. Geol. Sur. I-Map 2480. [50] Morris, E.C., and Tanaka, K.L., 1994, U.S. Geol. Sur. I-Map I-2327.

MECHANICAL ABRASION AS A LOW COST TECHNIQUE FOR CONTAMINATION-FREE SAMPLE ACQUISITION FROM A CATEGORY IVA CLEAN PLATFORM B. Dolgin[1], C.Yarbrough[1], J. Carson[1], and R. Troy [1]. [1]Jet Propulsion Laboratory, California Institute of Technology.

The proposed Mars Sample Transfer Chain Architecture provides Planetary Protection Officers with clean samples that are required for the eventual release from confinement of the returned Martian samples. At the same time, absolute cleanliness and sterility requirement is not placed of any part of the Lander (including the deep drill), Mars Assent Vehicle (MAV), any part of the Orbiting Sample container (OS), Rover mobility platform, any part of the Minicorer, Robotic arm (including instrument sensors), and most of the caching equipment on the Rover. The removal of the strict requirements in excess of the Category IVa cleanliness (Pathfinder clean) is expected to lead to significant cost savings.

The proposed architecture assumes that cross-contamination renders all surfaces in the vicinity of the rover(s) and the lander(s) contaminated. Thus, no accessible surface of Martian rocks and soil is Eath contamination free. As a result of the latter, only subsurface samples (either rock or soil) can be and will be collected for eventual return to Earth.

Uncontaminated samples can be collected from a Category IVa clean platform. Both subsurface soil and rock samples can be maintained clean if they are collected by devices that are self-contained and clean and sterile inside only. The top layer of the sample is removed in a manner that does not contaminate the collection tools. Biobarier (e.g., aluminum foil) covering the moving parts of these devices may be used as the only self-removing bio-blanket that is required. The samples never leave the collection tools. The lids are placed on these tools inside the collection device. These single use tools with the lid and the sample inside are brought to Earth in the OS. The lids have to be designed impenetrable to the Earth organisms. The latter is a well-established art.

Uncontaminated soil collection devices are the simplest to design though a similar device can be designed for coring. The soil collection device relies on the following approach (see Figure 1):

- Scrape the top layer of soil while covering it with a clean clean lid
- Collect the sample from beneath it
- Close the collection device inside the clean enclosure.
- Shed the enclosure and deposit the sample still in the collection device into the OS.

It appears that the samples collected in the prescribed manner will be exposed only to aluminum (or another metal preferred by the PP officers) cleaned to the best level the 2002 technology will allow. The cleanliness of the sample is guaranteed by design, its verification does not require biological assaying, and, if required, the verification can be performed in-situ.

Feasibility of the Earth contamination free regolith sample collection described above has been demonstrated. Currently, the probability that a single dust particle with an Earth microorganism attached to it makes its way to the collected sample has been reduced to below 10^{-8}. The latter means, that if each and every microorganism permited on a Category IVa clean spacecraft is deposited onto the immediate areas where the samples are collected and only onto those areas, the probability that a single Eath based organism will be found in the return sample is blow 1%. Obviously this is the worst-worst case scenario, and the actual probability of a round-trip Earth organism is much lower. Further improvements of the technique are expected.

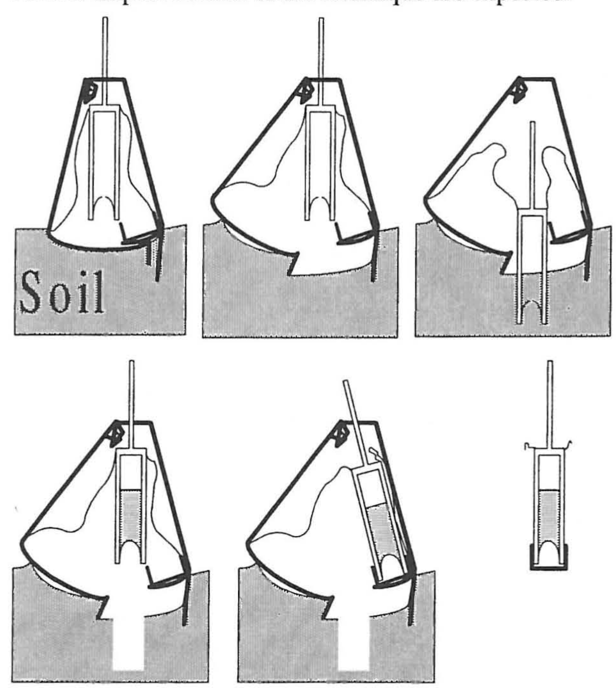


Figure 1. Sequence of steps to procure Earth-contamination free sample using a collection tool placed inside a device that is clean on the inside but

Martian Chronology: Goals for Investigations from a Recent Multidisciplinary Workshop. P. T. Doran[1], T. E. Cerling[2], S. M. Clifford[3], S. L. Forman[1], L. Nyquist[4], D. A. Papanastassiou[5], B. W. Stewart[6], N. C. Sturchio[1], T. D. Swindle[7], [1]Earth Environmental Science (MC 186), University of Illinois at Chicago, Chicago, IL 60607-7059, [2]University of Utah, Department of Geology & Geophysics, Salt Lake City, UT 84112, [3]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston TX 77058, [4]NASA Johnson Space Center, Houston, TX 77058, [5]Jet Propulsion Laboratory, Caltech, Pasadena, CA, [6]Department of Geology & Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260, [7]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721.

Introduction: The absolute chronology of Martian rocks and events is based mainly on crater statistics and remains highly uncertain. Martian chronology will be critical to building a time scale comparable to Earth's to address questions about the early evolution of the planets and their ecosystems. In order to address issues and strategies specific to Martian chronology, a workshop was held, 4-7 June 2000, with invited participants from the planetary, geochronology, geochemistry, and astrobiology communities. The workshop focused on identifying: a) key scientific questions of Martian chronology; b) chronological techniques applicable to Mars; c) unique processes on Mars that could be exploited to obtain rates, fluxes, ages; and d) sampling issues for these techniques. This is an overview of the workshop findings and recommendations.

Table 1. Martian epochs and their model ages [1].

Epoch	Maximum age (Ga)
Early Noachian	4.6
Middle Noachian	~4.5 to 3.92
Late Noachian	~4.3 to 3.85
Early Hesperian	3.8 to 2.5
Late Hesperian	3.7 to 1.3
Early Amazonian	3.55 to 0.6
Middle Amazonian	1.8 to 0.25
Late Amazonian	0.5 to 0.1

Scientific Questions (chronologic targets).

Calibrating the long-term Mars cratering rate. To calibrate the Martian cratering rate and improve chronology based on crater statisitics, the most critical date to acquire is Hesperian to middle Amazonian. Additional Noachian and late Amazonian dates should be acquired to check for changes in the cratering rate over time. Desirable units for dating are igneous rocks having pristine cratering records (i.e., unbrecciated). By dating the largest impacts on the planet (e.g., Hellas), absolute global time horizons may be established.

Major volcanic events. Volcanic flows are probably the best types of deposits to constrain the impact cratering rate. It is important to establish the ages of volcanic features and address questions regarding the timing and long-term trends in global volcanic activity which may be related to the fluvial events discussed below. Chronologic and related isotopic information on the oldest volcanic rocks may provide insight into early planet-wide processes, such as core formation, crust-mantle differentiation, and the possibility of plate tectonics, early in Martian history.

Ancient and recent fluvial activity. While most hydrologic activity on Mars is thought to be ancient (pre-Amazonian), high-resolution MOC images suggest recent fluvial activity on the surface of Mars (<10^7 a BP) as well [2]. Hypotheses invoking changes in Mars obliquity [3] and internal processes [4] have been put forth to explain how liquid water might be generated on the surface during the present epoch. Discrimination between these possible origins will require both *in situ* confirmation of their true nature and accurate dating of their occurrence. Data on the history of surface water on Mars would help constrain the environmental conditions during the Noachian, which in turn would help constrain models for prebiotic chemistry, protobiology, the possible origin and evolution of life, and the potential transfer of life between Mars and Earth.

Polar layered terrain. As the planet's principal cold traps, the Martian polar regions have accumulated extensive mantles of ice and dust that cover ~10^6 km^2 and are as much as 4 km thick [5]. The scarcity of superimposed craters on their surface suggests that these deposits are relatively young (<10^8 a). Their layering allows for a temporal calibration of global events (e.g., volcanic eruptions, dust storms, large impacts, etc.) that can be used as chronological markers elsewhere.

Chronology Techniques Applicable to Mars.

Nuclear techniques. Radiogenic dating by the K-Ar system (including ^{40}Ar-^{39}Ar) will be applicable to the >10^5 a window for dating volcanic lava flows or widespread ash deposits (e.g., in the polar layered terrain). An application of radiogenic dating to the history of water on Mars is the use of the K-Ar or Rb-Sr methods to date evaporite deposits, especially K-rich salts, and possibly co-existing carbonates. Radioactive parent-daughter dating schemes will be directly applicable (K-Ar, Rb-Sr, Sm-Nd, U-Th-Pb, Lu-Hf, Re-Os, and short-lived systems, e.g., Hf-W, Mn-Cr, I-Xe, Pu-Xe, ^{146}Sm-^{142}Nd). If there is recent (<10^6 a) activity on Mars, U-Th decay series methods can be used to determine the: a) ages of young lava flows or pyroclastic deposits; b) ages of waterlain spring deposits, evaporites, and hydrothermal deposits/alterations; and c) atmospheric residence times of aeolian particulates.

Cosmogenic techniques. The production rates for cosmogenic nuclides on Mars will allow for exposure dating of samples within the 10^7 a range. Events and processes that may be datable using cosmogenic nuclides include: a) erosion (i.e., by floods, landslides, glaciation); b) deposition age of previously deeply buried material (erosion and deposition by glacial processes, floods, etc); c) faulting (tectonic scarps); and d) volcanic or impact events. The history of aeolian dust may also be measurable, allowing trapped dust in the polar layered deposits to be dated. The use of secondary neutron capture effects (e.g., in Gd, Sm) would permit the extension of studies of cosmic ray irradiation to the 10^9 a scale.

Luminescence dating. Luminescence dating techniques have been used successfully on terrestrial aeolian and fluvial deposits. On the Earth, during burial, minerals absorb natural radiation from isotopes of U, Th, and K, and from cosmic rays. The absorbed radiation leads to a metastable concentration of electronic charge "trapped" at defect sites within the minerals' crystal lattice. The trapped charge is proportional to the absorbed radiation dose and can be determined by induced fluorescence. Luminescence techniques for Mars require consideration of: a) the higher cosmic ray flux; b) uncertainties in the mineralogy of Mars materials; and c) the effects of extremely cold temperatures. Windblown sediments may be suitable for dating in the $<10^5$ a range. The greatest potential for this technique would be *in situ* use in the polar layered terrain.

Mars-specific chronometers.

Stable isotopes of nitrogen. The unique isotopic composition of nitrogen in the Martian atmosphere may permit a Mars-specific "chronometer" for tracing the time-evolution of the atmosphere and of lithic phases with trapped atmospheric gases. Theoretical models predict a nearly linear increase of $\delta^{15}N$ from near zero to the present-day value of ~620‰ [6, 7]. The time rate of change of $\delta^{15}N$ could be calibrated by measuring $\delta^{15}N$ in nitrogen extracted from secondary phases of rocks (e.g., impact glass) with ages measured by standard radiometric techniques. Subsequent measurement of $\delta^{15}N$ in a nitrate, for example, would determine the time of nitrate deposition. The secular variation in the isotopic compositions of other atmospheric gases (O, C, H, Ar) also could be used to determine independent estimates of the deposition time.

Gas Fluxes. The goal of flux investigations is to establish the rates of volatile transfer from the Martian crust to the atmosphere, most likely by molecular diffusion. Data on volatile species, such as He, Rn, CO_2 and H_2O, can then be used as a prospecting tool to define areas of recent hydrologic processes (deep saline ground water or trapped hydrothermal fluids).

Platinum Group Elements (PGE). Measuring the abundance of PGE in Martian soils would provide a measure of the accumulated influx of micrometeorites to the Martian surface. The initial component of Martian PGE should have been partitioned into the core at its formation. The lack of crustal recycling on Mars would allow the accumulation of PGE on the Martian surface over long periods. The effects can address surface (regolith) gardening by meteorite impacts.

Recommendations. The workshop focused on key science questions and solutions. General recommendations on sampling were made:

Context and background. For useful chronometric information, it is essential to know the geological (stratigraphic) context of the samples. Knowing the chemistry of the samples is also critical for most applications. In addition, there are certain baselines that need to be known, such as the present composition of the atmosphere (and trace species of interest) and the chemical and physical characteristics of current dust.

Multiple techniques. For any chronometric determination, an age on a single sample determined by a single technique is unlikely to be useful. For full confidence in the results, it is preferable to measure ages by multiple techniques on multiple samples. If a single technique is to be used (e.g., in situ), it must be shown to give consistent results on multiple samples.

Technique development. Most of the techniques described require further development for use on Mars. For *in situ* sampling, funds must be committed early enough to allow for design, miniaturization and thorough testing and calibration. For a sample return mission, questions of environmental requirements for the samples and planetary protection must be considered.

Acknowledgements. The authors are the workshop organizing committee and discussion leaders. This abstract is based on the input of the participants: P. Beauchamp, L. Borg, C. Budney, G. Cardell, F. Carsey, J. Christensen, J. Cutts, A. Davis, S. Guggenheim, J. Kargel, D. Kossakovski, K. Lepper, G. McDonald, C. Mckay, S. McKeever, R. Morris, K. Nizhiizumi, F. Podosek, R. Poreda, J. Rice, M. Taylor, K. Tanaka, M. Wadhwa. The workshop was supported by the Mars Program Office, JPL (Contract #1215592).

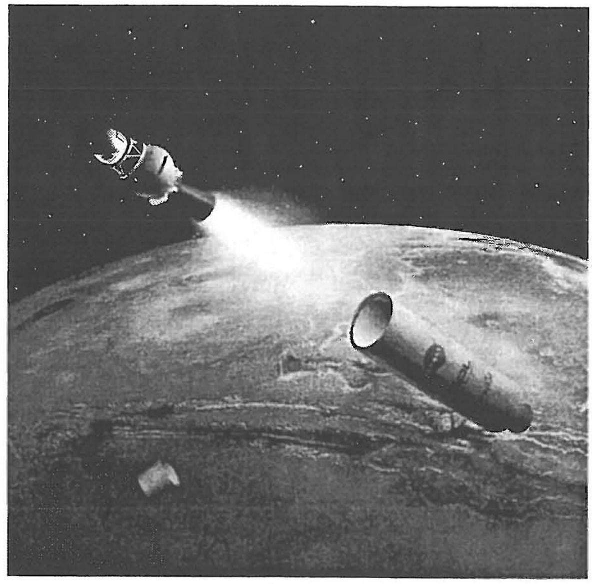
References: [1] modified from Tanaka, K.L. (1986) *JGR* **91**, E139. [2] Malin, M. & K. Edgett (2000) *Science* (in press). [3] Parthare A. V. & D. A. Paige (1998) *First Inter. Conf.* [4] Baker V. R. et al. (1991) *Nature* **352**, 589-594.. *Mars Polar Science Exploration*, p. 31, LPI, Houston. [5] Clifford S. M. et al. (2000). *Icarus* 144, 210-242. [6] Pepin, R. O. (1994) Icarus 111, 289-304. [7] Jakosky, B.M. et al. (1994) Icarus 111, 271-288.

Enabling Launch Vehicle Technology for Mars Sample Return Missions. M. Dorsch[1], B. Patel[2], and A. Mauritz[3], [1]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, dorsch.mike@orbital.com, [2]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, patel.bhavesh@orbital.com, [3]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, mauritz.ann@orbital.com

Sample return missions constitute an important element of the overall strategy for the exploration of Mars. A launch vehicle (booster) is required to successfully transfer samples from the Martian surface to orbiting spacecraft. This booster must survive harsh Martian environments while providing high performance within tight mass and power constraints.

Leveraging its unparalleled expertise at the successful development of new small launch vehicles, Orbital Sciences Corporation (Orbital) developed a booster system for NASA JPL's Mars Ascent Vehicle (MAV) study and RFP in 1999. The MAV was an integral element in the overall Mars Sample Return (MSR) architecture.

The figure illustrates Orbital's design concept. The booster is a two-stage, solid rocket system that can launch approximately 6 kg into a 500 km circular orbit around Mars. The booster system total mass is less than 135 kg, while the design accommodates stringent planetary protection requirements and complex interfaces with the lander. Operationally, the system requires minimal interaction with mission controllers for launch preparations. It possesses the capability to erecting itself from a stowed position to the desired initial launch azimuth.



Solid rocket motors designed for long duration space exposure are provided by Thiokol based on heritage from its proven Star series. The Guidance, Navigation, and Control (GNC) system is based on Orbital's highly proven Pegasus and Taurus launch vehicles. The lightweight booster avionics hardware derives extensive heritage from Orbital's spacecraft programs.

In addition to the MSR scenario, there exist other mission implementations where the sample is not necessarily returned to Earth for analyses, but is instead analyzed onboard a spacecraft in Mars orbit. Orbital's booster systems is capable of supporting either mission scenario.

EXTRACTION OF WATER FROM THE MARTIAN REGOLITH, M. B. Duke[1], R. M. Baldwin, R. H. King, R. D. Knecht, T. Muff, and B. Holland, Colorado School of Mines, Golden, CO 80401 [1](mikeduke@earthlink.com)

Access to usable water on Mars is important for human missions. Water would be used for life support and as a source of rocket propellant. Among the potential sources of water that have been discussed are extraction from the atmosphere [1], permafrost [2], and subsurface liquid water [3]. The most ubiquitous and widespread source of water is likely to be bound water in the regolith, which would have to be obtained by heating the regolith to 500° C. Whereas this may seem complicated and energy-intensive, we are studying small (~20kg each) robotic systems for regolith excavation and thermal extraction capable of producing an amount of water per year approximately 30 times the combined mass of equipment required, including the power supply for the extraction system. At this production capacity an integrated system could produce in one year an amount of water equivalent to about 3 times the mass of hydrogen that would have to be transported to produce the same amount of water. In practice, this would be approximately 6 times better than bringing hydrogen from Earth, when the mass of the tanks needed to transport the hydrogen is also considered.

Several types of excavators are possible that can meet the performance requirements. One concept, based on a student design study conducted in the fall of 1999, envisions a mobile drag-line system. Draglines are typically used on Earth for sand and gravel excavation. The Martian system would use an extendable arm of light-weight material (e.g. graphite-epoxy) to extend a bucket about 5 m from a rotating hub on a central processing station. The bucket is extended to the end of the arm, dropped to the surface where it enters with a downward motion and is then dragged by cables toward the central hub until it fills. The bucket is literally dragged across the surface, so the configuration places little torque on the central hub and the arm, which can be quite stable. The drag-line could be operated in any direction, so could acquire sample from at least 180° around the central station. Assuming that the bucket can collect 5 kg of sample and will complete a cycle every 15 minutes, it could collect 20 kg of regolith an hour. Assuming that it could reach to an average of 20cm beneath the surace, approximately 25 mt of material would be accessible before the rig would have to be moved, equivalent to an operating time of 1250 hours of operation. If the Martian regolith contains 2% water by weight, this would be enough regolith to produce 500 kg of water. Bench-top models of the excavator are being designed.

The central processing station is designed to heat the regolith to 500°C, driving off the water, which can be condensed on a cold plate in a separate section of the station. Thermal control is a very important aspect of this element of the system, and material flows must allow for the hot, dry solids at one end of the system to preheat the incoming regolith. Several approaches to this problem have been considered. In modeling this system, we have assumed that solar photovoltaic cells would be utilized, the mass of which must be included in the system mass.

The performance of the system can be determined using simulants. We expect to test the system utilizing JSC-Mars 1 and a mixture of kaolinite and silica glass as Mars surface regolith simulants.

The actual or predicted performance of the system depends on a better understanding of the characteristics of the Martian regolith. The only analytical information on water content is that reported from the Viking GCMS experiments [4]. These data suggest that there may be as much as 2% bound water, released at temperatures between 200°-500°C. Phobos mission IR spectroscopic data have been interpreted to indicate as much as 4% water in the regolith [5]. Much more data is required from Martian regoliths. These include the mineralogical constitution of water-bearing phases in the regolith, the amount of adsorbed water, the size distribution of the water-bearing phases, and the distribution of excavatable regolith. Whereas the surface of Mars at landing sites so far investigated appears to be rocky, there may be significant areas where easy access to fine-grained regolith materials is possible. One important question is whether the composition of the material that makes up dunes is sufficiently water-rich to be of interest, as these would make deposits that are relatively straightforward to excavate and would have a smaller range of grainsizes, making the reactor design simpler.

References:

[1] Coons, S. C. et al (1995) *Journal of the British Interplanetary Society* 48,347-354 (updated at http://www.aa.washington.edu/research/ISRU/JBIS/)
[2] Squyres, S. W. et al (1992) in H. Kieffer et al (Eds.), Mars, 523-554.

[3] Jakosky, B. M. and A. P. Zent (1993) in J. S. Lewis, Resources of Near Earth Space, 737-763.
[4] Biemann, K., J. Oro, P. Toulmin III, L. E. Orgel, A. O. Nier, D. M. Anderson, P. G. Simmonds, D. Flory, A. V. Diaz, D. R. Rushneck, J. E. Biller and A. L. LaFleur (1977), The Search for Organic Substances and Inorganic Volatile Compounds in the Surface of Mars, *Jour. Geophys. Res.* **82**, pp. 4641-4658
[5] Yen, A. S. et al (1998) *Jour. Geophys. Res.* 103, 11,125-11,133.

Flight Validation of Mars Mission Technologies: P. J. Eberspeaker, Goddard Space Flight Center, Wallops Flight Facility, Building F-6, Wallops Island, Virginia 23337, Philip.J.Eberspeaker.1@gsfc.nasa.gov

Introduction: Effective exploration and characterization of Mars will require the deployment of numerous surface probes, tethered balloon stations and free-flying balloon systems as well as larger landers and orbiting satellite systems.

Since launch opportunities exist approximately every two years it is extremely critical that each and every mission maximize its potential for success. This will require significant testing of each system in an environment that simulates the actual operational environment as closely as possible. Analytical techniques and laboratory testing goes along way in mitigating the inherent risks associated with space exploration, however they fall sort of accurately simulating the unpredictable operational environment in which these systems must function.

Flight Validation Approach: Goddard Space Flight Center's Wallops Flight Facility (WFF) is currently engaged in developing techniques that can be used to flight validate future Mars systems such as atmospheric entry bodies, planetary aircraft, and planetary balloon systems. The proposed approach follows a "stepping stone" methodology that allows sub-scale and/or full-scale prototypes to be tested under real-world conditions. When appropriate, various test platforms can be employed to systematically expand the operational envelope of the test object. For example, terrestrial balloon systems (Figure 1) can be used for initial drop tests for decelerator systems and balloon inflation systems. Suborbital rockets (Figure 2) can be used to investigate atmospheric entry dynamics and high speed atmospheric descent. Typical Mach numbers that can be achieved using selected sub-orbital rockets are provided in Table 1.

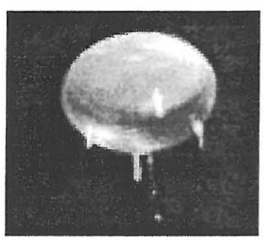


Figure 1
Terrestrial Balloon

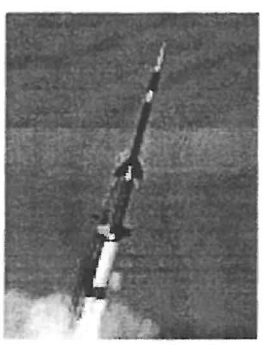


Figure 2
Sub-Orbital Rocket

Vehicle System	Descending Mach Number
Nike-Orion	4
Terrier-Black Brant	7-8
Black Brant XII	10

Table 1
Sub-Orbital Rocket Capabilities

Finally, the Space Shuttle can then be used to investigate reentry body flight characteristics at orbital velocities. The proposed concept will rely on existing shuttle hardware so that costs can be minimized.

Test Sites: Tests with small impact dispersions can be conducted at existing land-based ranges (i.e. White Sands Missile Range) while systems with larger or invalidated impact dispersions can be conducted at Wallops Flight Facility. Wallops Flight Facility offers a large recovery range and is currently developing techniques for recovering small payloads far out to sea.

Atmospheric Entry Body Testing: Wallops Flight Facility has teamed with Ames Research Center (ARC) and is currently engaged in flight experiments on various atmospheric entry bodies including rigid aeroshells, flexible aeroshells, and hypersonic lifting bodies. One flight test has already been conducted on a number of small aeroshell technologies including the rigid and flexible aeroshells and a Linear Aerobrake system for high L/D atmospheric entry systems [1]. The next test is scheduled for October 2000, and is designed to demonstrate the technologies associated with the deployment, data collection and recovery of multiple reentry bodies and decelerator systems. Secondary objectives include the actual investigation of the dynamic behavior of a hypersonic lifting body (Figure 3) as it transitions from space flight to atmospheric flight. This test will also include a second demonstration flight of the Linear Aerobrake system.

Figure 3
ARC Lifting Body

Balloon System Development / Testing: Wallops Flight Facility is also in a strong position to conduct an end-to-end test program to demonstrate technologies required for the deployment and inflation of a free-flying balloon system on descent above an altitude of 31 km (Earth). Wallops Flight Facility is the center for NASA's terrestrial balloon program and possesses a significant portion of the technical expertise in this area. As part of the balloon program, Wallops Flight Facility owns and operates a state-of-the-art balloon systems laboratory and is currently engaged in developmental activities that will benefit Mars ballooning. The flight validation of this system will follow the phased methodology outlined earlier.

Mars UAV Flight Validation: Wallops Flight Facility's UAV experience coupled with balloon and rocket carrier systems are ideal for accomplishing flight verification testing on Mars UAV concepts.

Wallops Flight Facility proposes that flight validation testing be conducted on all critical Mars technologies before they are applied to specific missions. This approach will mitigate risks and enhance the probability that a large network of small probes can be placed on Mars in an efficient and cost effective manner. The in-house expertise at Wallops Flight Facility is well suited for this activity and is already engaged in flight validation of technologies critical to future Mars exploration.

[1] The Linear Aerobrake, M. Murbach, Ames Patent Disclosure, 1999

GEOCHEMISTRY ON FUTURE MARS MISSIONS. T. E. Economou[1], C. N. Foley[2] and R. N. Clayton[1, 2], [1]Enrico Fermi Institute, University of Chicago, 933 East 56th Street, Chicago, IL 60637, tecon@tecon.uchicago.edu [2]Department of the Geophysical Sciences, University of Chicago, Chicago, IL 60637.

Introduction: The determination of the geochemistry of Mars should be one of the most important goals of future missions to Mars. The detailed determination of the chemical composition of Martian soil and rocks will contribute significantly to understanding the origin and history of the planet Mars. The results of the Pathfinder mission demonstrated that the APXS technique is the method of choice for in-situ chemical analysis of rocks and soil. Some version of this instrument should be flown on all future lander missions to Mars to provide answers to many of the questions about the geochemistry of Mars. The APXS determines the elemental composition for all elements (except H, He). The results of analysis from the X-ray mode and from the alpha/proton modes are partially redundant and partially complimentary and there is excellent agreement between the two modes for elements that are analyzed by both. Especially important is the ability of the APXS instrument to determine the light elements (C, N, O) because of their important role in organic matter.

Pathfinder Results: The Pathfinder APXS provided us with the chemical composition of soil and for the first time with the chemical composition of Martian rocks at the Pathfinder landing site. In order to understand the composition of Mars it is imperative to obtain rock compositions from as many sites as possible.

Even the preliminary examination of the Pathfinder APXS data has led to several significant geological interpretations: [1] 1) the rock surfaces analyzed have coatings, to varying degrees, of Martian dust; 2) the "dust" component may be algebraically subtracted in order to reveal the compositions of the underlying rocks; 3) the rocks are more silica-rich than typical terrestrial basalts; 4) the Pathfinder soil is very similar in composition to the Viking fines [2]. The dust is exceptionally rich in magnesium and sulfur, and contains significant amounts of chlorine, posing a puzzle as to the origin of this material.

Potential habitats for biological activity are likely to be characterized by the presence of compounds of hydrogen, carbon and nitrogen. Carbon and nitrogen are directly measurable by the α-mode of the APXS; hydrogen contents can be inferred from excess oxygen, which is also directly measured by APXS. Carbonates on the surface of Mars have also been sought remotely by spectrometric methods, but not yet detected. No carbon signal was found in the Pathfinder APXS analyses, implying a concentration limit below 0.3 wt percent in the rocks and soils at the Pathfinder site.

Future Instrument Development for Martian Analyses: *The 2001 or 2003 APEX.* The Pathfinder APXS has been modified and calibrated, through a joint analysis program between the University of Chicago and the Max-Planck Institut, for flight on either the 2001 or 2003 lander. The Pathfinder design was modified to reduce the atmospheric signal contributing to the alpha mode. A comparison of the alpha spectra from the Pathfinder flight instrument and the APEX 01 or 03 instrument which illustrates this atmospheric signal reduction is shown in Figure 1. In addition, the APEX APXS was upgraded with a new X-ray detector with a resolution much better than that of the Pathfinder APXS. The most recent versions of the X-ray PIN detectors achieve almost the resolution of the LN_2 cooled Si(Li) detectors.

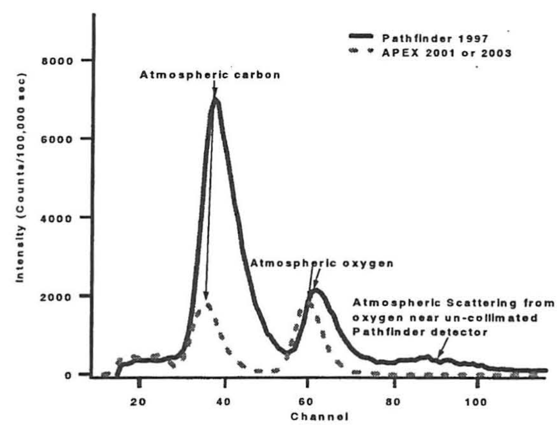


Figure 1: Be target in 9 mbar Martian atmosphere for Pathfinder and APEX instruments showing a reduction in the amount of atmospheric contribution with the newer design.

The smaller MUSES-CN AXS for future Mars missions. Another instrument similar to Pathfinder has been designed, built, and tested at the University of Chicago [3] for flight on the joint Japanese ISAS and NASA Muses-CN mission to the asteroid ML 1989. A photograph, as well as its general characteristics, are shown in Table 1 and Figure 2 below. The AXS could very well be used on any future Mars mission.

As a consequence of its tight geometry and smaller physical size, the AXS is less affected by the CO_2 atmosphere in the alpha mode and it is at the same time five times more efficient in the X-ray mode even with the half of the radioactive source intensity. Its lightweight and compact design could enable easy mounting on a robotic arm for obtaining the analysis of selected samples and for characterization of samples on sample return missions. Its performance is equal or superior to the Pathfinder APXS.

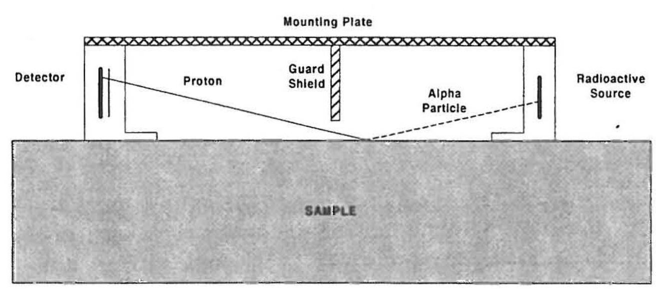
Table1: AXS Characteristics for MUSES-C Mission

Weight:	**95 grams**
Volume:	**65 cm^3**
Power :	**<200 mW**
Voltages:	**+7.5 V DC**
	-7.5 V DC
Radioactive Source:	**30 mCi of Cm-244**
E_α:	**5.8 MeV**
$T_{1/2}$:	**18.1 years**
Data Requirements :	**10 kb / spectrum**
Accumulation Time:	**0.5-3 hours/ sample**

Figure 2: AXS prototype for MUSES-C Mission

Water Determination on the Surface of Mars. The determination of any water on the Martian surface on a future mission to Mars is of utmost importance for many reasons: understanding the influence of bonding water on mineralogy, its significance for life development, and its significance as a resource for future manned missions to Mars. The APXS cannot determine the presence of water directly, but water can be deduced from any excess of oxygen over that needed from the stoichiometry assuming the highest oxidation state. Other instruments (e.g. Mössbauer spectrometer) could provide the oxidation state of iron. By slight modification of the APXS so that it can work in a forward scattering mode (instead of back-scattering mode), the APXS can be made to determine directly any hydrogen present in the sample. The direct hydrogen and oxygen determination will uniquely measure the concentration of water in the Martian samples.

Semiconductor detectors and radioisotope sources of alpha-particles of the proposed experiment are similar to detectors and sources which were used in the APXS experiment, but their geometrical configuration will be different and more suitable for registration of forward-scattered particles. The sketch of sensor block of the proposed experiment is shown in Figure 3.



MARS NETWORK: STRATEGIES FOR DEPLOYING ENABLING TELECOMMUNICATIONS CAPABILITIES IN SUPPORT OF MARS EXPLORATION, C. D. Edwards[1], J. T. Adams[1], J. R. Agre[1], D. J. Bell[1], L. P. Clare[1], J. F. Durning[2], T. A. Ely[1], H. Hemmati[1], R. Y. Leung[2], C. A. McGraw[2], S. N. Rosell[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, [2]Goddard Space Flight Center, Greenbelt, MD 20771. *e-mail: chad.edwards@jpl.nasa.gov*

Introduction: The coming decade of Mars exploration will involve a diverse set of robotic science missions, including *in situ* and sample return investigations, and ultimately moving towards sustained robotic presence on the Martian surface. In supporting this mission set, NASA must establish a robust telecommunications architecture that meets the specific science needs of near-term missions while enabling new methods of future exploration. This paper will assess the anticipated telecommunciations needs of future Mars exploration, examine specific options for deploying capabilities, and quantify the performance of these options in terms of key figures of merit.

Anticipated Telecommunications Needs: Various classes of Mars science missions can be characterized by their telecommunications needs and constraints.

Remote Sensing Orbiters: Highly capable deep space links will be required to provide global, high-resolution, multi-spectral mapping of Mars. For example, consider a high-resolution three-color visible imager. Mapping the entire planet at 1m resolution represents an uncompressed data volume of about 5000 Terabits. This enormous data volume, if it were to be returned in a single Martian year, translates to an average continuous data rate of over 100 Mb/s, roughly three orders of magnitude larger than current Mars-Earth links. Aggressive use of data compression along with increased deep space link performance will be required to achieve such science goals.

Large In-Situ Landers/Rovers: In situ surface exploration will demand both increased data return and connectivity. Data volume requirements will be driven by science needs as well as operational considerations. For example, a single three-color stereo panorama, imaged with 1 mrad resolution, represents about 0.5 Gb of data. Increases in rover mobility will naturally drive an increase in desired data return, as the number of "independent" sites visited will scale with rover traverse range. In addition to data volume, communications link availability will be an important consideration, particularly for complex surface operations. Finally, all landed missions will desire telecommunications visibility and support during entry, descent, and landing, to provide full characterization of EDL systems in the event of any anomaly.

Small Scouts/Aerobots/Microprobes: These missions are characterized by their small size (<100 kg) and highly constrained energy budgets. Typically, they cannot afford the mass and energy required for any meaningful data return directly over a deep space link. Rather, these missions require, and are enabled by, energy-efficient relay communications. Concepts range from single-element scouts or aerobots, communicating directly to an orbiting relay satellite, to "sensor webs" consisting of large numbers of extremely small microprobes carrying out focused, collaborative science via inter-element communications links.

Sample Return Missions: In addition to all the considerations which apply to large lander/rover missions, sample return will also require critical real-time telemetry support during launch of a Mars Ascent Vehicle as well as radio tracking for orbit determination and rendezvous with an Orbiting Sample Canister (OSC).

Potential Mars Network Elements: A variety of techniques and communications elements are candidates to meet these needs.

Direct-to-Earth Links: Orbiter data return, either for remote sensing science orbiters or for telecom relay orbiters, is limited by the deep space comm link capability. Use of high-power traveling wave tube amplifiers (>100W) can increase data rates to over 100 kbps at X-band. Use of DSN 70m apertures (not recommended for extended operations) or transition to Ka-band offers further 6 dB performance increases in the near term. Migration to optical communications wavelengths offers a longer-term path to further growth in deep space comm channel capability. A prototype is currently in development for a next-generation multi-functional optical instrument with capability for narrow-angle (high-resolution) science imaging, optical navigation and ranging in addition to optical communication at data rates 100's of kbps from Mars. NASA's longer-term optical comm roadmap forecasts Mars-to-Earth link capabilities in excess of 10 Mbps.

Landed vehicles will be constrained to much smaller mass, power, and volume for any direct-to-Earth links, and hence lower data rates. Mars Pathfinder utilized a link with a 30cm antenna and 15W radiated power, corresponding to a link capability of less than 1 kbps to a DSN 34m antenna at maximum Earth-Mars distance. In addition, surface energy constraints typically limit use of this direct link to a small fraction of a sol. On the other hand, because Earth is above the horizon for most of the sunlit portion of a Mars sol, direct-to-Earth links are useful for low-rate command and telemetry for large rovers/landers during surface operations.

Short-range Surface-to-Surface Communications: Multi-element missions, such as a lander and rover carrying out sample return, will require low-power, low-mass *in situ* comm links. Sensor webs will demand even lower-power, highly integrated comm systems. Wireless RF solutions will highly leverage terrestrial commercial developments, while novel free-space optical approaches utilizing scanning lasers and modulatable retro-reflectors offer extremely low-power solutions.

Low-Altitude Orbiters with UHF Relay Capability: Because of their low slant ranges to surface users, low-altitude orbiters can support extremely energy-efficient, high-rate UHF (400 MHz) links from the surface of Mars, even when utilizing operationally simple omnidirectional links on both the surface and orbital spacecraft. This makes these orbital assets of prime importance for small scouts, aerobots, and microprobes characterized by highly constrained mass and energy budgets and inability to point highly directional communications antennas. Typical UHF link performance for omni-to-omni links scales roughly as $\frac{32\,kbps \times (P_T / 1\,W)}{(R\ /\ 1000\,km)^2}$, so a typical 10W lander radio can achieve rates of up to 1 Mbps to a low-altitude orbiter when it passes overhead.

Two primary classes of low-altitude orbiters have been considered. Science orbiters are typically deployed in low (~400km) sun-synchronous polar orbits in order to support global, high-resolution remote sensing. Adding a UHF proximity link telecommunications payload to these orbiters is an extremely cost-effective way to add to the Mars orbital telecommunications infrastructure. On the other hand, the polar orbit implies short (5-10 min), infrequent (typically twice per sol) contacts for near-equatorial landers, where most near-term missions will be targeted. The second option is dedicated telecom satellites, deployed into optimal orbits to support planned surface activity. For instance, an equatorial orbiter at an altitude of 800 km can support 12 passes per sol for an equatorial lander, with coverage out to +- 30 deg latitude.

Constellations of 3-6 low-altitude orbiters can provide global coverage, frequent contact every 1-2 hrs, and data return of 1-10 Gb/sol for future Mars exploration, along with intrinsic robustness and resilience to the loss of a single element. In addition, crosslink observations between constellation orbiters can yield accurate atmospheric profiles globally distributed in Mars latitude and longitude.

Mars Areostationary Relay Satellites: An areostationary satellite is the Mars-equivalent of an Earth geostationary satellite. From the areostationary altitude of 17,000 km, a Mars Areostationary Relay Satellite (MARSAT) would have continuous visibility of a landed surface vehicle. Utilizing directional links, data rates of 1 Mbps can be achieved from a modest surface radio (e.g., 20 cm antenna, 5 W radiated power). With a high-capability Earth link, MARSAT can thus enable end-to-end data transfer of up to 1 Mbps from the Martian surface back to Earth, capable of supporting streaming video or other high-bandwidth applications. The primary challenge of a MARSAT mission is the high cost of achieving areostationary orbit. Chemical propulsion requires a large propellant mass which drives the mission to a Delta III-class launch vehicle. Solar Electric Propulsion options are being explored as potential lower-cost alternative for an areostationary orbiter. MARSAT would also provide an interesting science platform for visible or IR imagers in terms of characterizing global-scale atmospheric phenomena.

Elliptical Orbiters: By the time of the workshop, we will also have new results to present for the telecommunications performance of a mini-constellation of two elliptical orbiters. Such a design appears to offer some of the advantages of MARSAT, such as much higher connectivity than low-altitude orbiters, without the high delta-V costs of achieving areostationary orbit.

Integrated Information/Communications Architecture: Design of the communications network supporting Mars will greatly benefit from integrating *in situ* information processing for science and support operations. Greater efficiencies may be expected by performing local processing and subsequent transport of the processed information, rather than simply communicating raw high-bandwidth sensor data. These gains primarily stem from the reduced energy consumption of computation versus communications. Bandwidth is also better utilized. Increased processing tends to produce outputs characterized by smaller volume (in terms of bits needed to represent them) together with greater dynamics and unpredictability. In order to accommodate this increased variability using assets remotely operated on Mars, new and adaptive communications protocols and information handling techniques are required.

Navigation Considerations: While the emphasis of this abstract has been on telecommunications, we will also report on the potential of these assets to provide radio Doppler and range tracking for support of precision approach navigation, surface navigation, and MAV/OSC navigation.

Analysis: Based on different candidate program science strategies, pros and cons of various combinations of these telecommunications options will be characterized quantitatively in the presented paper in terms of key figures of merit, including data return, connectivity, operational simplicity, cost, and risk.

Acknowledgments: The research described in this report was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

MARTIAN SURFACE BOUNDARY LAYER CHARACTERIZATION: ENABLING ENVIRONMENTAL DATA FOR SCIENCE, ENGINEERING AND HUMAN EXPLORATION.

C. England, Jet Propulsion Laboratory, M/S 233-103, 4800 Oak Grove Drive, Pasadena, CA, 91109, cengland@jpl.nasa.gov

Introduction: For human or large robotic exploration of Mars, engineering devices such as power sources will be utilized that interact closely with the Martian environment. Heat sources for power production, for example, will use the low ambient temperature for efficient heat rejection. The Martian ambient, however, is highly variable, and will have a first order influence on the efficiency and operation of all large-scale equipment. Diurnal changes in temperature, for example, can vary the theoretical efficiency of power production by 15% and affect the choice of equipment, working fluids, and operating parameters.

As part of the Mars Exploration program, missions must acquire the environmental data needed for design, operation and maintenance of engineering equipment including the transportation devices. The information should focus on the variability of the environment, and on the differences among locations including latitudes, altitudes, and seasons. This paper outlines some of the WHY's, WHAT's and WHERE's of the needed data, as well as some examples of how this data will be used.

Environmental data for engineering design should be considered a priority in Mars Exploration planning. The Mars Thermal Environment Radiator Characterization (MTERC), and Dust Accumulation and Removal Technology (DART) experiments planned for early Mars landers are examples of information needed for even small robotic missions. Large missions will require proportionately more accurate data that encompass larger samples of the Martian surface conditions. In achieving this goal, the Mars Exploration program will also acquire primary data needed for understanding Martian weather, surface evolution, and ground-atmosphere interrelationships.

Environmental Data Needs: Mechanical and thermal systems that operate for extended periods on the surface of Mars will require complete environmental information that describes the surface boundary layer. Seasonal and diurnal changes in temperature can change the density of the atmosphere over 40%, affecting how open-atmosphere turbogenerators, for example, must be designed. Even closed cycle Brayton engines, baselined for the Mars Reference Mission, must reject heat into highly variable surroundings. Designers must be provided with enough information to adapt the technologies to a particular Martian location.

At each location, simultaneous readings that provide pressure, temperature and density are needed. This combination will provide classic P-V-T information. With wind vector data, dust characterization and thermal radiation data, the local energetics can be established that aid both engineering and scientific enterprises. Full characterization requires information on composition changes as well. These changes, while expected over seasonal time periods, may also be appreciable on the diurnal cycle.

Variability: Changes in environmental parameters within the surface boundary layer are known to occur diurnally and seasonally from Viking and Pathfinder data. Measurements at these three locations demonstrated variability of conditions at the surface that is not detectable from orbiting spacecraft. Planners for human-tended missions will require surface environmental information not only on shorter-term time periods, but over at least several years to establish knowledge of weather cycles with confidence. Weather predictions as much as two years in advance may be required by the long times for Mars transit.

Diurnal variations in temperature and pressure have a primary effect on thermodynamic equipment such as power systems. They also affect photovoltaic design and operating parameters as well as other exposed devices. Combined diurnal and seasonal variations are expected in composition because the Martian poles act as sources and sinks for carbon dioxide in amounts up to 30%. Design for recovery of resources relies on a good understanding of the atmospheric composition.

Location: P-V-T, wind velocity and radiation data are most valuable when acquired globally so that the Martian weather can be best understood. All latitudes should be represented in a network of measurements designed to understand the surface boundary layer environment. Locally, data within craters, canyons and plains would be especially valuable for determining underground composition and possible human landing site options. Stations at large mountains or volcanoes might provide excellent data to confirm weather predictions.

Users of Environmental Data: Scientists and engineers will use the P-V-T and vector information as primary research and design tools. Scientists will be given the ability to create sophisticated models of Martian surface weather that incorporate planet-wide thermodynamic data. While of enormous scientific value, these models will help guide the design human exploration missions. Weather prediction will be an essential part of successfully establishing and maintaining a human presence on the planet.

Engineers will use the comprehensive environmental data to design, locate, operate and maintain equipment on the surface of Mars. For example, the Mars Atmosphere Resource Recovery System (MARRS) being developed under NIAC sponsorship by the author is an open cycle processing system that removes oxygen, water and other compounds directly from the Martian atmosphere, and returns the unused material back to the atmosphere. For a rational design, data inputs require not only P-V-T information, but also daily and seasonal variations in atmospheric composition. MARRS and other systems must be designed to accommodate at least a 30% daily change in inlet pressure.

Designers of all equipment in contact with the Martian environment will use the data set for selection of materials, qualification requirements, operating parameters and other design factors. Designing for the environmental variability will be a unique aspect of Martian exploration.

EXPLORATION OF MARS USING AERIAL PLATFORMS. D. A. Fairbrother[1], S.M. Raque[2], I.S. Smith[3], J. A.Cutts [4], V. Kerzhanovich[5], [1]GSFC-Wallops Flight Facility, Balloon Program Office, Code 820, Wallops Island, VA 23337, [2]GSFC-Wallops Flight Facility, Wallops Island, [3]GSFC-Wallops Flight Facility, Wallops Island, [4]Jet Propulsion Laboratory, Pasadena, CA, [5]Jet Propulsion Laboratory, Pasadena, CA.

Introduction: The exploration of the atmosphere of Mars can be conducted using aerial platforms such as balloons and airships. Current research and development efforts at NASA include a lobed pressurized balloon system for the Ultra Long Duration Balloon Program. The capabilities of this system, in regards to pressure, load carrying capability, and duration, are far greater than anything previously flown. This technology can be adapted for use in the atmosphere of Mars.

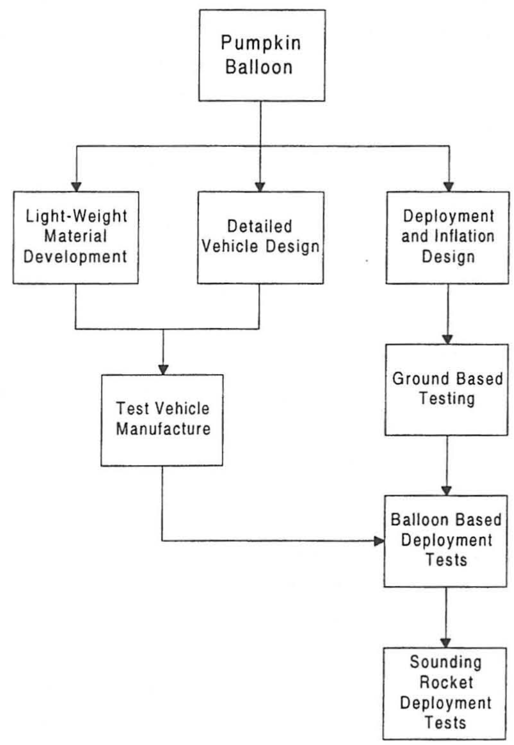
Mission Concept: The traditional scientific balloons flown are "zero-pressure" balloons which are limited in duration due to the diurnal temperature effects on the lift in the system. The duration of flight can be extended with a pressurized system. The pressure in the system will be affected by the diurnal cycle, but as long as it remains pressurized, it will float at a constant density altitude. NASA's Ultra Long Duration Balloon (ULDB) Program is utilizing a pressurized lobed or "pumpkin" balloon to extend the flight duration to the order of 100 days. The smaller radius of curvature in conjunction with load carrying tendons of this balloon reduce the stress requirements of the material. Since weight is so critical in planetary applications, the transition from a spherical balloon to a pumpkin balloon increases the pressure capability while reducing the material strength requirements.

The pumpkin balloon allows for longer missions which, depending on the wind currents, will provide for more coverage of the atmosphere and the planet's surface.

Design Validation: There are several efforts developing different balloon systems for Mars. In conjunction with JPL, WFF is developing a pumpkin balloon for planetary applications as part of a Cross Enterprise Technology Development Program; however, the balloon is not the focus of this effort. The deployment and inflation system is the primary focus of this effort.

In the balloon development, several areas need to be focused on. First, high strength to weight materials are required to provide the largest load carrying capability for the smallest system weight. In addition, there is great potential that new manufacturing techniques will be required to fabricate the balloon. As has already been done by JPL in some other efforts, ground based and balloon based depolyment tests are required. The inflation system under development by JPL can be utilized for these efforts. A final validation test would be deployment of the balloon system from a sounding rocket . This will better simulate the entry of the system into the atmosphere of Mars.

The flow of the validation process is shown below :



Strategies for the Astrobiological Exploration of Mars

Jack Farmer (Arizona State University)

Introduction

The search for evidence of past and present life and/or prebiotic chemistry has been identified as the primary focus of the current Mars Surveyor (MS) Program. In this context, recent exploration strategies have emphasized the need to explore three basic geological environments **(1)**: A) sites of ancient surface water, B) sites of ancient subsurface water and C) sites of present subsurface water. In previous implementation strategies it has been generally assumed that if subsurface water exists on Mars today it will be located at a depth of several km **(2)**. Access will require deep drilling that is beyond the capabilities of current robotic platforms **(3)**. Logically, the exploration for deposits of ancient hydrological systems may be much easier and has, therefore, given priority. However, recent discoveries from the Mars Global Surveyor (MGS) mission have demonstrated that we still have a lot to learn about past and present Martian environments and the potential for life. Advances in our understanding of Martian surface topography, geomorphology **(4)** and composition **(5)**, as well as in our knowledge of life in extreme environments on Earth **(6,7)**, indicate the value of considering a broadly-based, flexible strategy that will balance elements of both Exopaleontology (the search for a fossil record) and Exobiology (the search for extant life). Because exploration strategies for past and present life are fundamentally different **(8)**, it is appropriate to consider each separately before seeking to define a program architecture that will effectively combine both aspects during future robotic exploration.

Exploring for a Fossil Record

Important clues to guide the search for a evidence of an ancient Martian biosphere can be gleaned from studies of the fossil record on Earth, as well as modern geomicrobiological systems that are analogs for the early biosphere. The most basic requirement for life is widely regarded to be liquid water, which is a universal necessity for life as we know it. One underlying assumption is that if life ever started on Mars, it's origin and evolution was controlled by the distribution of liquid water. Hence, the current dictum of Mars exploration, "follow the water" (Carl Pilcher, personal comm. 2000). Tracing the past distribution of aqueous habitats is a necessary first step in implementing exploration for ancient life. This means identifying the distribution of aqueously-formed sediments that are the most likely repositories for fossil information. But the <u>search for ancient water is only a first step</u>. Studies of the Precambrian fossil record and of microbial fossilization processes in modern Earth environments, indicate that preservation is common in only a few types of geologic settings **(9)**. These environments typically share certain features in common, including: A) the rapid deposition of sediments under conditions favorable for life and B) the incorporation of organisms or their by-products into impermeable host sediments of stable mineralogy (e.g. silica, phosphate, or carbonate). The Archean fossil record on Earth is basically preserved in two types of sedimentary deposits: A) fine-grained, clay-rich detrital sediments and/or water-lain pyroclastics and B) finely crystalline chemical sediments (e.g. evaporite deposits of terminal paleolake basins, spring deposits, (inclusive of hydrothermal) and mineralized zones (hard-pans) within ancient soils). The most reliable basis for identifying the paleoenvironments cited above is mineralogy. Thus, mapping the distribution of aqueous mineral deposits is of paramount importance for implementing missions to explore for a record of past life **(10)**.

As noted, the systematic exploration for a Martian fossil record will depend critically upon locating accessible surface outcrops of aqueously-formed sediments which possess the preservational properties identified above. Logically, exploration should begin by mapping the distribution of high priority sedimentary deposits from orbit to provide the precursor information needed to target landed missions to the most favored sites for *in situ* exploration and sample return. This effort could be optimized by acquiring high spatial resolution remote sensing data over a broad range of wavelengths be able to identify discrete mineral signatures from complex mixtures. To further reduce risk in site selection, orbital observations of high priority sites need to be confirmed by *in situ* surface exploration. Because the modern Martian regolith and surface soils do not provide favorable environments for the preservation of fossil biosignatures, landed missions need to be able to analyze rocks **(10)**. The most definitive fossil biosignatures are typically microscale geochemical and/or microfabric features. Thus, sample return followed by detailed study in Earth-based labs will probably be required for definitive answers **(1)**. It is also likely that discover fossil biosignatures, we will need to sample returns from several different types of sites **(1)**.

Given the science requirements, proper sample selection for return to Earth will be of paramount importance. This can be best accomplished by the use of properly equipped mobile science laboratories that can survey and sample a broad range of lithotypes at a site . The Athena payload has been optimized for this task. Crucial instrument capabilities needed for sample selection include *in situ* mineralogical analysis (e.g. by surface spectral methods), the ability to access unweathered interior rock surfaces (e.g. by coring or chipping) and capabilities for imaging rock surfaces at hand lens magnifications (x10-20).

Exploring for Extant Life

The exploration for extant Martian life must take a fundamentally different path than that just outlined for Exopaleontology **(8)**. The crucial element of this strategy is to locate potentially habitable zones of liquid water in the Martian subsurface. Prior to deep (multiple km) drilling by humans it may be possible to access near-surface liquid water "oases" that could sustain life or prebiotic chemistry using surface robots. The potential for subsurface hydrothermal systems sustained by magmatic sources within the shallow crust **(e.g. 11, 12)** could provide for the convective upflow of subsurface water into the shallow cryosphere. Where recent upflows of subsurface water have replenished near surface aquifers, subsurface miroroorganisms or prebiotic chemistry may have been incorporated into shallow ground ice. Depending on the geologic context, such sites would provide direct robotic access to cryopreserved organic materials through shallow drilling. Locating the most favorable sites for such investigations could be undertaken initially from orbit by searching for spatially confined thermal anomalies and/or localized concentrations of vapor emissions (e.g. water and/or reduced gases like methane). Recent observations favor the presence of zones of basal melting within polar ice caps **(13)**. This suggests an alternative site type, namely periglacial (marginal polar) environments where sub-glacial outfloods of the Icelandic type **(14)** may have occurred. These are logical targets for robotic exploration. Outflow features possibly formed this way have recently been identified adjacent to both polar caps on Mars, providing exciting new opportunities for future exploration.

References:

(1) NASA, 1996. Mars Expeditions Strategy Group (D. McCleese, Chair) Unpublished report. (http://www.hq.nasa.gov/office/oss/mccleese.html); **(2)** Clifford, S.M. J. Geophys. Res. 98, 10973-11016, 1993; **(3)** NASA, Mars Deep Drilling Workshop (Briggs, G., Organizer), unpublished report, 1996. **(4)** Head III, James W. et al., *Science* 286, 2134-2137, 1999; **(5)** Christensen, P.R., et al., *J. Geophys. Res.*, 105, 9623-9642, 2000; **(6)** Stevens, T.O., and J.P McKinley, *Science* 270, 450-454, 1996; **(7)** Siegert, Martin J., *American Scientist* 87:6, 1999; Karl, D.M., et al., *Science* 286, 2144-2147, 1999; **(8)** Farmer, J. D., *Palaios* 10 (3), 197-198, 1995; **(9)** Farmer J. D. and D. J. Des Marais, *Journ. Geophys. Res.* 104 (E11), 26,977-26,995, 1999; **(10)** Farmer, J.D., p. 58-65, *In* Julian Hiscox (Editor) *The Search for Life on Mars*, Special Issue, *Brit. Interplanet. Soc.,* London, 1999; **(11)** Farmer, J.D., pp. 273-299, *In* G. Bock, and J. Goode (eds) *Evolution of Hydrothermal Ecosystems on Earth (and Mars),* John Wiley & Sons Ltd., Chichester, 1996; **(12)** Gulick, V., *Journ. Geophys. Res.*, 103 (E8), 19,365-19,387, 1998; **(13)** Clifford, S.M., *J. Geophys. Res.* 92 (B9), 9135-9152, 1987; **(14)** Brandsdóttir, B., http://www.hi.is/~mmh/gos/photos4.html, 1996.

ELECTRICAL CHARGING HAZARDS ORIGINATING FROM THE SURFACE (ECHOS): UNDERSTANDING THE MARTIAN ELECTRO-METEOROLOGICAL ENVIRONMENT. W. M. Farrell[1], M. D. Desch[1], J. R. Marshall[2], G. T. Delory[3], J. C. Kolecki[4], G. B. Hillard[4], M. L. Kaiser,[1] R. M. Haberle,[5] A. P. Zent[5] ,J. G. Luhmann[3], R. Greeley[6], S. A. Cummer[7], D. Crisp[8], D. C. Catling[5], M. G. Buehler[8], G. W. Thomas[9], and D. D. Sentman[10] ,[1] NASA/Goddard SFC, [2] SETI Inst./NASA Ames, [3] UC Berkeley,[4] NASA/Glenn RC, [5] NASA/Ames RC, [6] Ariz. St. Univ., [7] Duke Univ., [8] Jet Propulsion Lab, [9] Univ of Iowa, [10] Univ. Of Alaska

Introduction: In 1999, the NASA/Human Exploration and Development of Space (HEDS) enterprise selected a number of payloads to fly to the Martian surface in an 03 opportunity (prior to the MPL loss). Part of a proposed experiment, ECHOS, was selected to specifically understand the electrical charging hazards from tribocharged dust in the ambient atmosphere, in dust devils, and in larger storms[1]. It is expected that Martian dust storms become tribocharged much like terrestrial dust devils which can possess almost a million elementary charges per cubic centimeter [2,3].

The ECHOS package features a set of instruments for measuring electric effects: a radio to detect AC electric fields radiating from discharges in the storm,a DC electric field system for sensing electrostatic fields from concentrations of charged dust grains, and a lander electrometer chain for determining the induced potential on its body and MAV (Mars Ascent Vehicle) during the passages of a charged dust storm.

Given that electricity is a systemic process originating from wind-blown dust, we also proposed to correlate the electrical measurements with fundamental fluid/meteorological observations, including wind velocity and vorticity, temperature, and pressure. Triboelectricity will also affect local chemistry, and chemical-sensing devices were also considered a feature of the package.

The primary HEDS objectives of the ECHOS sensing suite is to discover and monitor the natural electrical hazards associated with dust devils and storms, and determine their enviro-effectiveness on human systems. However, ECHOS also has a strong footprint in the overarching science objectives of the Mars Surveyor Program.

References: [1] Farrell, WM et al., (2000) *Acta Astronautica 46,* 25-36. [2] Freier, G. D., (1997) *JGR, 65,* 3504. [3] Farrell, WM et al., (1999) *JGR, 104,* 3795-3801.

Technologies and Their Integration for an Unmanned Aircraft for Mars Exploration Richard J. Foch[1], Jill P. Dahlburg[2], Joseph F. MacKrell[3], Gregory S. Page[4], [1]Code 5712, Naval Research Laboratory, 4555 Overlook Ave., Washington DC 20375-5000, foch@ccs.nrl.navy.mil, [2]Code 5703, Naval Research Laboratory, 4555 Overlook Ave., Washington DC 20375-5000 dahlburg@lcp.nrl.navy.mil, [3]Code 5713, Naval Research Laboratory, 4555 Overlook Ave., Washington DC 20375-5000, joe@ccs.nrl.navy.mil, [4]ITT, Systems & Sciences Corp., 2560 Huntington Ave., Alexandria, VA 22303-1410 gregory.s.page@nrl.navy.mil .

Introduction: The development of aircraft for Mars exploration highlights the critical importance of all-up system optimization for achieving a high-value mission. Requisite technologies for flight-deployed, autonomous unmanned air vehicles (UAVs) have been developed and refined during the past 25 years by the Naval Research Laboratory for a broad range of military and civilian applications. The research and development of these technologies provide a background of practical experience, design tools, and a heritage of over two dozen, flight-tested, unmanned aircraft designs. The application of this practical knowledge towards planetary exploration could enable the development of unmanned aircraft for the exploration of Mars that takes advantage of substantial Navy and DOD investment in UAVs, autonomous operations, and remote sensing.

Mars Airplane Technologies: Cutting edge technology Navy UAVs are demonstrating the level of fully autonomous operation needed to enable the development of an affordable, unmanned aircraft capable of successfully deploying and operating in the Martian atmosphere. These have included: self-deployment, following release from high speed tactical aircraft; self navigation using inertial sensors, optical sensors, and other non-GPS techniques; non air-breathing propulsion; high aerodynamic efficiency at low Reynolds number flight conditions; advanced aerospace composite deployable structures; robust, highly adaptive autopilot architectures; and affordable expendability. Aircraft flight control and navigation on Mars is analogous to that on Earth, prior to the introduction of GPS navigation or any other significant radio aids. Thus, all of these technologies are applicable to planetary exploration with an unmanned air vehicle. A more challenging flight control issue will be the fact that a Mars airplane, unlike any terrestrial aircraft, will be performing its very first test flight as its one mission flight. A highly adaptive autopilot will be required to adjust, in real time, for conditions and factors unforeseen by terrestrial simulation and testing.

Technology Integration: The realization of a successful Mars airplane will require a design that takes advantage of the requisite technologies to provide the simplest system that can meet the mission goals. Integration is the key to developing a system that mitigates risks while becoming simpler rather than more complicated. For example, uncertainties in the performance of airfoils at the very low Reynolds flight conditions add a high uncertainty with regard to propeller performance. However, if one selects a rocket-propelled configuration, or a glider, the propulsion efficiency uncertainty is removed and the overall becomes simpler.

Objective: This paper will discuss the requisite technologies for an unmanned aircraft for planetary exploration, and the integration of these technologies into optimal and simple configurations for flight in the Martian atmosphere.

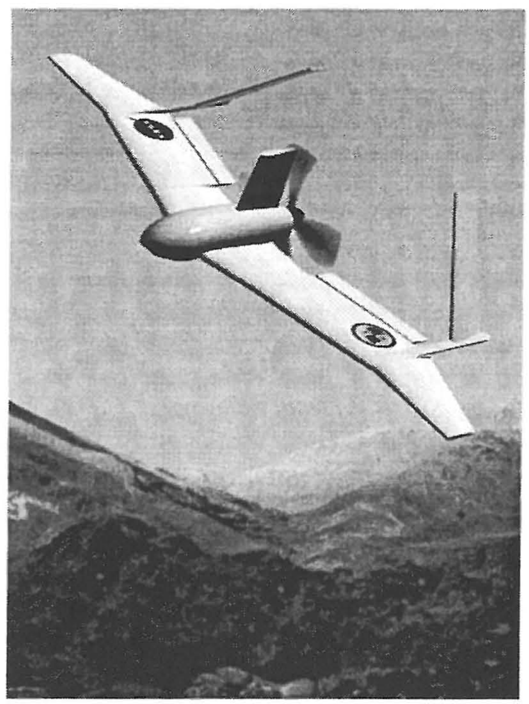


Figure. Depiction of unmanned flight on Mars.

MARTIAN ICE CAVES. R. D. Frederick, T. L. Billings, R. D. McGown, B. E. Walden[1], [1]Oregon L5 Society, Mars Instrument and Science Team, P.O. Box 86, Oregon City, OR 97045 email: gus@norwebster.com

Introduction: Ice in Martian lava tube caves would have scientific and developmental value. These natural channels in rock may hold keys to Mars' past as well as potential resources for humanity's future.

Rationale: Terrestrial lava tube caves are natural receptacles for accumulations of water. Often, due to lower temperatures coupled with the superior insulation properties of the surrounding rock, these accumulations are in the form of ice. Historically, ice was mined from some lava tube caves (Fig. 1). Many of the lava tubes in the Central Oregon area sport such names as "Arnolds Ice Cave," "Surveyors Ice Cave," "South Ice Cave," etc. These caves are not caves in ice, but rather common lava tubes with seasonal, and sometimes perennial ice deposits. Locating and cataloging similar features on Mars, could be of value for the colonization of Mars and the search for life. Such features may also prove useful in helping to determine past climatic conditions on the Red Planet.

Figure 1. 19th century Central Oregon ice miners pose with large blocks of ice quaried inside Arnold Ice Cave. *(Local Postcard)*

Explanation: On Earth, where climate and cave structures are favorable, freezing air settles into lava tube caves and is kept below freezing by basalt insulation (Fig. 2) When the weather warms, liquid water flows into the cave and freezes solid. The layers of water can freeze year after year, sometimes completely filling the cave. In this way, records of past climate can be preserved in the ice. Debris, including organic debris, washed into the cave can be frozen and preserved. During past warm and wet periods on Mars, these same mechanisms may well have existed.

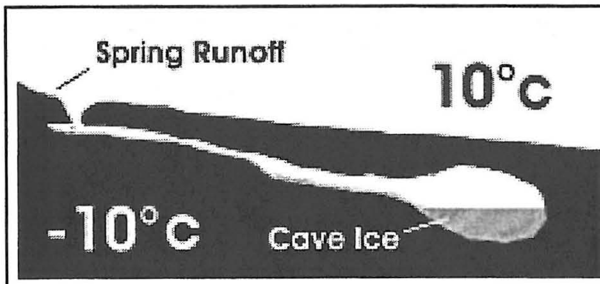


Figure 2. A typical lava tube "Ice Sink." Surrounding basalt keeps the air below freezing. Spring runoff flowing into the cave freezes when it comes in contact with the colder air. Some ice deposits are perennial, eventually filling the cave. *(Diagram by R.D. Frederick)*

Scientific Value: Cave ice deposits can be important for a number of reasons. First and foremost, the ice has potential for use by Mars explorers and settlers. The ice may also contain various components that could answer a number of questions about Mars. Trace elements could provide records of past climates. By analyzing layers of different deposits and (or) dissolved gases, a better picture of the Mars of yesteryear could be obtained. Materials washed into the cave and frozen in the ice can show what surface conditions existed in the past. This would be especially important in determining how these conditions were different than today. Gas bubbles preserved in ice could provide a snapshot of an earlier Martian atmosphere. Long term climate fluctuations could be preserved in the ice record.

If life was able to grab a foothold on an earlier, more benign Martian surface, actual samples may be found in these natural deep freezers. If Martian life was similar to that found on our planet, it will be closely linked and dependent upon water. Elements of frozen Martian life may in fact be preserved more effectively than on the surface, because the caves are sheltered from the sterilizing surface conditions. If water is present, life may have adapted and evolved and may still exist there today. Ice cave deposits on the Earth often show dark green features, painted by the hand of life (Fig. 3).

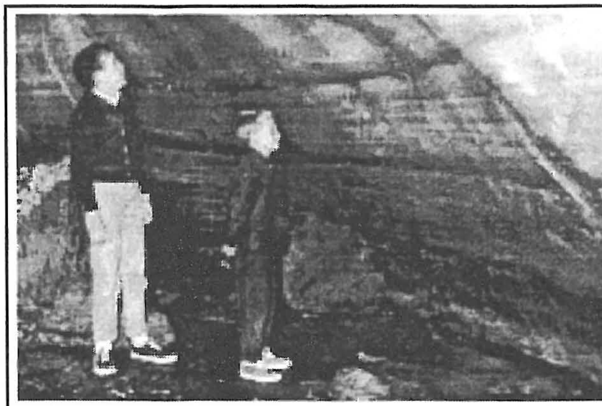


Figure 3. Two young cavers examine dark green bands of life preserved in the walls of a terrestrial ice cave.

Remote Detection of Cave Ice: Direct detection of cave ice deposits from orbit may prove difficult, if not impossible to accomplish. Secondary effects associated with lava tubes may be possible to detect however. Many terrestrial caves were discovered in this manner. Some caves on Earth "breathe" due to the inertial lag in equalizing the large cave volume when outside air pressure changes. Valentine Cave in northern California was discovered on a clear cold winter day by observation of a steam-like cloud plume rising from the entrance[1]. The Lavacicle lava tube in Central Oregon was discovered by firefighters, mopping up after a large forest fire. One of the crew observed a column of clean air rising through the fire's smoke, and discovered an entrance into the cave [2]. Similar effects may occur in the still, dusty air after one of Mars' frequent dust storms. By analyzing the densities of suspended dust above surfaces of lava flows, we may be able to effectively detect "exhaling" entrances to these caves. Aeolian deposits around cave entrances may be an indicator of this effect.

Other techniques, such as surface-deployed ground-penetrating radar, might prove useful to detect cave ice deposits. The radar signal responds to changes in dielectric constant of different materials that might indicate the presence of ice. Likewise, a radar "flashbulb" might be employed, making use of kinetic energy to create a loud radar "burst" that would yield similar data. However, other techniques may be necessary to locate potential sites before this technique could be employed. A neutron reflectance spectrometer might be made to work, which would detect ice signatures. Sonographic techniques such as geologists use to identify buried features may be able to detect cave voids, but discriminating the signature of ice may be problematical.

Finding lava tube caves on Mars is pretty easy, in that numerous indicators of lava tubes have been identified from orbit as far back as Viking, with new data from MGS providing a better view. However, where to look for lava tubes that may contain water is a different matter. Most of the volcanic areas of Mars are located in higher elevations, such as the Tharsis plateau. Assuming that wet, warm conditions in the past were conducive to water drainage into cold caves, logically we should narrow our search to those tubes located in lower areas.

Recent data from the Mars Global Surveyor mission has identified additional flood zones on the Red Planet. One large one is adjacent to the Olympus Mons volcano [3]. Indeed, it would appear that this most massive of shield volcanoes is perched in the northwest section of a peninsula jutting out into an ancient northern sea. Just northeast of these new, bigger flood channels are extensive lava flows that may be of a low enough elevation to have captured potential Martian rain showers.

It is our opinion that the northwest flanks of this area would be an ideal place to look for such features. A host of igneous flow features, including lava tubes, have been identified in this area. Combining this with its relative close proximity to the possible northern ocean, as well as a lower elevation than other similar areas, makes this an attractive area to search for ice caves. The ice within lava tubes may prove to be an ancient document of Martian maritime conditions.

Confirmation of Cave Ice: Once a candidate cave is located, the next step would be to examine it for signs of ice or other volatiles. Options may include the use of robotic "insects" communicating via a self-deploying, self-optimizing, cellular network, [4]. In this scheme, a series of "insect robots" enter the cave, and install a series of communications relays as well as a central "base" where they can periodically return to recharge power systems. These robots could also be used to map a cave as they go. A flying probe may turn out to be more practical than navigation over a rockfall-strewn cave floor.

Cave exploration appears to be a significant challenge to current robotics, and may require human explorers. Of course, those explorers will need to be in communication with their peers on the surface. Several schemes for this have been proposed, such as optical fiber deployment, extra low frequency radio, sonic transmission through rock, and low-frequency free air acoustical signaling. The latter method may even be an effective way of determining the density of gases within caves.

Developmental Value: Lava tube caves could be desirable sites for long term habitation on Mars, due to the natural shielding afforded by the thick layers of basalt making up the structure [5]. Habitats built in lava tubes would not require extensive shielding, and could in fact be nothing more than tough inflatable domes. Light could be channeled in with large inflatable versions of "Solatube" skylights, making use of the same effects that fiber optics use, only without the mass. A large, long inflatable cylinder with mirrored sides could bounce light into a cave. Owing to the reduced gravity, Martian lava tube caves would dwarf their terrestrial counterparts. Finding an available deposit of frozen water may add the frosting to the cake, making lava tube habitats not only possible, but desirable.

References: [1] Larson, C & J (1990) "*Lava Beds Caves*", footnote, 12. [2] Larson, C. V. (1982) "*An Introduction to Caves of the Bend Area*", 48. [3] Dohm, J. M., Anderson, R. C., (2000) *Sky and Telescope*, "Newsfronts: More Martian Floods?" June, 2000 Vol. 99/No. 6, 24. [4] Boston, P. J. (2000) NASA Tech Memo, "Human Utilization and Exploration of Subsurface Extraterrestrial Environments: Technologies and Test Beds". [5] Walden, B. E. 1988. "Lunar base simulations in lava tubes of the Pacific Northwest". AAAS Pacific Region Meeting, Corvallis, OR. June, 1988."

MARS OXIDANT: PROOF OF CONCEPT AND QUANTITATIVE ANALYSIS.

Friedemann Freund[1], Aaron Staple[2], Paul Gosling[3], and Warren Belisle[4], ([1] NASA Ames Research Center, Moffett Field, CA 94035 (ffreund@mail.arc.nasa.gov; [2] Stanford University, [3] San Jose State University, [4] Lockheed-Martin Engineering.

Introduction: Textbooks make us believe that in every silicate mineral, on Earth, Mars and elsewhere, the oxygen anions exist in just one oxidation state, namely 2- as in O^{2-}. Yet, a surprisingly large fraction of the oxygen anions in rock-forming minerals may exist in a more oxidized form, namely the 1- state, as O^- in peroxy. This has far-reaching consequences for understanding the Mars soil oxidant and its biocompatibility.

The change from the 2- oxidation state to the 1- states starts with hydroxyls $O_3Si\text{-}OH$ that become incorporated into nominally anhydrous minerals whenever such minerals crystallize in an H_2O-laden magma [1]. Magmatic systems on Mars are surely H_2O-laden. During cooling, probably between 400-600°C, as the structures of the minerals are already frozen with respect to major diffusional rearrangements, $O_3Si\text{-}OH$ pairs reshuffle their electrons in such a way as to turn into peroxy links,

$$O_3Si/^{OH}{}_{HO}/SiO_3 = O_3Si/^{OO}\backslash SiO_3 + H_2 \quad (1)$$

This reaction is a classical redox reaction. What is quite unusual about it is (1) it takes place in the mineral structure, (2) oxygen acts as the electron donor, reducing hydroxyl protons to H_2, while oxidizing oxygen from O^{2-} to O^{1-}, and (3) H_2 molecules may diffuse out over geological time, leaving the rock (system) with excess oxygen in form of peroxy.

Because this redox reaction is takes place when the minerals are no longer in equilibrium, it is thermodynamically allowed. Thus, even minerals that are considered reduced and that do contain reduced transition metal cations can acquire peroxy during their cooling from magmatic temperatures. If H_2 molecules diffuse out, the peroxy left behind represent a true oxygen excess.

For some time we thought that the concentration of peroxy in common rock-forming minerals would be relatively small, maybe in the tens ppm range. Using a new analytical technique we are now finding unexpectedly high peroxy concentrations. For instance in MgO crystals, grown from a highly reduced melt, the peroxy concentration exceeds 10,000 ppm per 10^6 O^{2-}. In a granite from Barre, VT, we find an average peroxy content around 3,000 ppm. In andesite, a volcanic rock believed to be present on Mars, we find a lower but still significant peroxy concentration of about 300 ppm.

Our analytical technique is simple. We take advantage of the fact that peroxy becomes thermally unstable upon heating above 400-600°C, disproportionating [2]:

$$O_3Si/^{OO}\backslash SiO_3 \rightarrow O_3Si/^{O}\backslash SiO_3 + 1/2\ O_2 \quad (2)$$

For analysis we crush minerals or rocks to a fine powder and heat them (9°C/min) in a stream of N_2 (40 ml/min containing 50 vol.-ppm O_2), measuring the O_2 evolution by means of an amperometric Y/Zr O_2 oxygen sensor developed for Mars [3].

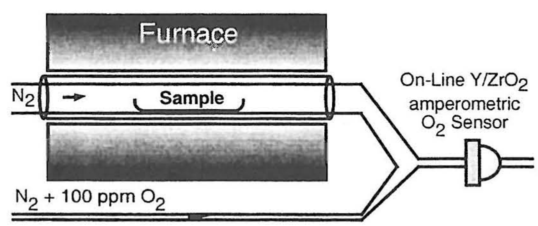


***Figure 1**: O_2 evolution experiment using an amperometric Y/ZrO_2 oxygen sensor.*

Figure 1 shows the set-up for the O_2 evolution measurements. The two gas streams, 20 ml/min each, one of pure N_2 and the other of N_2+100 ppm O_2, are combined after the furnace, because the operation of the Y/Zr O_2 oxygen sensor requires a small O_2 partial pressure.

Figure 2 shows the O_2 evolution from a crushed high purity (99.9%) MgO single crystal, measured with the Y/Zr O_2 oxygen sensor and verified by GC analysis. The O_2 evolution begins around 500°C and continues up to 600°C.

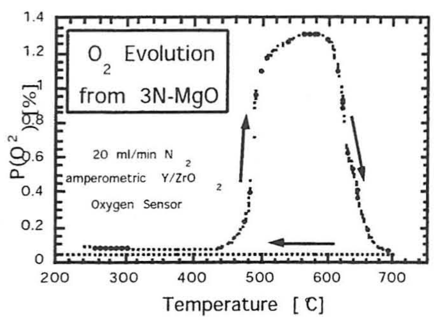


***Figure 2**: O_2 evolution from a crushed melt-grown MgO crystal.*

The total amount of O_2 released indicates that more than 1% of all O^{2-} anions in the MgO structure had converted to peroxy, O_2^{2-}. At the same time, as predicted by eq. (1), this MgO crystal contains H_2 molecules which give rise to a distinct IR band of H-H stretching combining with a lattice phonon at 4150 cm^{-1}. Given the fact that the MgO crystal had been grown the under extremely reducing conditions of a carbon arc furnace, the occurrence of peroxy is a confirmation of the type of redox conversion postulated by eq. (1).

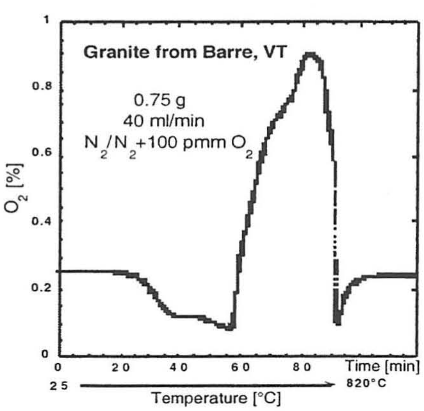


***Figure 3**: O_2 evolution from granite from Barre, Vermont.*

Figure 3 shows the O_2 evolution from a crushed sample of a granite from Barre, VT, measured in the same manner. The amount of O_2 released corresponds to about 3,000 ppm peroxy oxygen. At the time of writing of this abstract we do not yet know which minerals in granite are the peroxy-bearing and how much peroxy they contain.

Figure 3 also shows that, during heating, some O_2 in the carrier gas is consumed by side reactions either due to the combustion of reduced gases that evolve (CO or organics) or due to the oxidation of Fe^{2+} and other transition metal cations.

Mars is believed to have once been replete with water. Therefore, martian magmatic systems most surely were and may still be H_2O-laden. The minerals in martian igneous rocks that make up the surface regolith are likely to contain the same peroxy links as terrestrial rocks from similar environments.

Conclusion: (1) The amperometric Y/Zr O_2 oxygen sensor oxygen sensor [3] could be used to assess the amount of reduced gases and of molecular oxygen evolving from the Mars soil on heating. (2) Understanding the role the peroxy may play in igneous rocks on the surface of Mars may be crucial to understand the nature of the Mars oxidant. (3) This is crucial to understanding the properties of Mars soil and its biocompatibility.

References:

1. Freund, F., Conversion of dissolved "water" into molecular hydrogen and peroxy linkages., J. Non-Cryst. Solids 71, (1985): 195-202.
2. Cotton, F. A., and Wilkinson, G., Advanced Inorganic Chemistry, (New York: J. Wiley & Sons, 1980)
3. Sridhar, K. R., and Blanchard, J. A., Electronic conduction in low oxygen partial pressure measurements using an amperometric zirconia oxygen sensor, Sensors and Actuators B 59.1 (1999): 60-67.

CONNECTING ROBOTS AND HUMANS IN MARS EXPLORATION. Louis Friedman, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, tps.ldf@planetary.org.

Introduction: Mars exploration is a very special public interest. It's preeminence in the national space policy calling for "sustained robotic presence on the surface," international space policy (witness the now aborted international plan for sample return, and also aborted Russian "national Mars program") and the media attention to Mars exploration are two manifestations of that interest. Among a large segment of the public there is an implicit (mis)understanding that we are sending humans to Mars. Even among those who know that isn't already a national or international policy, many think it is the next human exploration goal. At the same time the resources for Mars exploration in the U.S. and other country's space programs are a very small part of space budgets. Very little is being applied to direct preparations for human flight. This was true before the 1999 mission losses in the United States, and it is more true today. The author's thesis is that the public interest and the space program response to Mars exploration are inconsistent.

This inconsistency probably results from an explicit space policy contradiction: Mars exploration is popular because of the implicit pull of Mars as the target for human exploration, but no synergy is permitted between the human and robotic programs to carry out the program. It is not permitted because of narrow, political thinking. In this paper we try to lay out the case for overcoming that thinking, even while not committing to any premature political initiative.

This paper sets out a rationale for Mars exploration and uses it to then define recommended elements of the programs: missions, science objectives, technology. That consideration is broader than the immediate issue of recovering from the failures of **Mars Climate Orbter, Mars Polar Lander** and the **Deep Space 2** microprobes in late 1999. But we cannot ignore those failures. They are causing a slow down Mars exploration. Not only were the three missions lost, with their planned science and technology investigations, but the 2001 **Mars Surveyor** lander; and an international cooperative effort for robotic Mars sample return were also lost.

But, NASA's emerging plan has bright spots, and certainly our presence at this workshop indicates a belief that the slow down is temporary. A 2003 rover with large range capability is a promising development. The fear about sample return must be addressed, and hopefully, it will be as the program re-starts. For our purposes we only have to recognize that Mars is the next human destination off Earth. And further that is the allure of humans to Mars that pull the robotic exploration program and generates the significant public interest behind the Mars program. With that recognition we can make sure the robotic program leads to human exploration. Bruce Murray has proposed that the robotic program be charged with supporting the human exploration goal and that steps toward development of a Mars outpost begin after the landers of 2003 and 2005. The outpost could be sited to meet objectives for the first human mission to Mars, but its development will begin with the establishment of robotic exploratory and infrastructure vehicles. These would include both scientific vehicles -- like rovers, aerial platforms, penetrators, etc., which use the outpost as a base -- and engineering systems, such as in-situ resource utilization systems for power or fuel production, communications satellites, beacons, drills, or even habitat modules. Certainly this is the place to debate the sample return strategy. Novel means of Mars exploration such as balloon and airplanes could also be included in this rationale. These are adjuncts to human explorers as well as robotic vehicles that can extend our range and capability for *in-situ* reconnaissance. How long the outpost remains robotic or how soon humans will actually fly there will depend on societal factors which will ultimately shape the political and economic decisions to that end.

A "level 0" requirement of the Mars robotic program is recommended: to select candidate landing sites for the first human mission to Mars -- the outpost site. (Doing this in the 2003-2008 time scale is perfectly reasonable, The data that will be used for such a selection will be less the analysis of returned samples and more the ancillary remote observations conducted in the Mars program). That site could be well imaged, and perhaps even the target for a small lander, penetrator, balloon or airplane in a "micromission." . With data about that site, interactive virtual reality models and posters could be available for the public and in schools – enabling the whole world to prepare for the human landing, by virtually exploring the outpost together. The political consensus could build simultaneous with the scientific knowledge and technical readiness for a human mission.

While visionary about human exploration, this recommendation requires nearly immediate action. The Mars architecture should include the outposts, so that resources and requirement from the human space program are applied. The international partners should join in this planning – Russia may even again become a player, once the space station is up. The "level 0" requirement of new Mars missions are being specified now. And, perhaps most importantly, the post-1998 Mars mission failures review being conducted now can make recommendations based on a clear vision of where the program is leading.

Mars exploration should not slow down nor should the human goal be set further off, because of the recent failures or for any other reason. The public support for pressing forward is no less. The people of Earth are engaged in a historic quest in the exploration of new worlds. Now is not the time to lose momentum.

PUBLIC PARTICIPATION IN PLANETARY EXPLORATION. Louis Friedman, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106, tps.ldf@planetary.org.

Introduction: In the past several years The Planetary Society has created several innovative opportunities for general public participation in the exploration of the solar system and the search for extraterrestrial life. The conduct of such exploration has traditionally been the province of a few thousand, at most, of professionally involved scientists and engineers. Yet the rationale for spending resources required by broad and far-reaching exploration involves a greater societal interest – it frequently being noted that the rationale cannot rely on science alone.

This paper reports on the more notable of the opportunities for general public participation, in particular:

Visions of Mars: a CD containing the works of science fiction about Mars, designed to be placed on Mars as the first library to be found by eventual human explorers.

MAPEX: a Microelectronics And Photonics Experiment, measuring the radiation environment for future human explorers of Mars, and containing a electron beam lithograph of names of all the members of The Planetary Society at a particular time.

Naming of spacecraft: Involvement in the naming of spacecraft: *Magellan, Sojourner.*

The Mars Microphone: the first privately funded instrument to be sent to another world.

Red Rover Goes to Mars: the first commercial-education partnership on a planetary mission.

Student designed nanoexperimens: to fly on a Mars lander.

SETI@home: a tool permitting millions to contribute to research and data processing in the search for extraterrestrial intelligence.

A brief description of each of the projects will be given, and the opportunity it provided for public participation described. The evolving complexity of these projects suggest that more opportunities will be found, and that the role of public participation can increase at the same time as making substantive contributions to the flight missions. It will be suggested that these projects presage the day that planetary exploration will be truly and global and mass public enterprise, with people in their homes, and in schools, in direct communication, and even control, of robotic devices on other worlds. The effect of this on future human and robotic exploration plans is considered.

Specific suggestions and plans for the Mars program will be offered – for the 2003, 2005 planned missions, for rovers, balloons and other aerostats, and for outposts leading to human flight. Partnerships among government and non-government organizations internationally and domestically and among different types of organizations contributing to education and public outreach will be discused.

An Affordable Mars Sample Return Mission. R. T. Gamber, B. M. Sutter, B. C. Clark, C. E. Faulconer, S. D. Jolly, Lockheed Martin (M.S. 8001, PO Box 179, Denver, Co 80201)

Introduction: High program cost has been a major reason that Mars Sample Return missions have not yet occurred. A low cost Mars Sample Return mission is proposed that can be launched in the 2005/2007 time-frame (see Fig. 1). This mission concept minimizes the total energy required by avoiding capture of the Earth Return Vehicle, ERV, at Mars. Deep Space Rendezvous, DSR, with a Martian sample offers significant cost savings over Mars Orbital rendezvous. The ERV rendezvous with the sample sphere is significantly simpler than under orbital conditions. The ERV propulsion system can use a simple monoprop design. The ERV carries a Sample Return Capsule (SRC) and the design is derived from the spacecraft for the Stardust comet sample return Discovery Mission. Many of the other hardware elements are derived from previous MSR project and concept studies by JPL and LMA.

Mission Concept: The Affordable Mars Sample Return Mission can be accomplished in this decade with conjunction class transfers to Mars and Type III returns to Earth. The landed element would be launched first on a direct entry trajectory to Mars. The ERV would be launched about 15 days later on a free return trajectory. Only Delta II - class launch vehicles are required. The MAV would launch from the Mars surface within 15 days of the ERV flyby and rendezvous would occur over the next few months in deep space as shown in Figure 2. A typical interplanetary trajectory is shown in Figure 3. The DSR concept was first published in 1995 in the reference.

Lander design. The lander would carry a two stage Mars Ascent vehicle and sample acquisition elements. The stay time on the martian surface is sufficient to acquire a diverse sample of 500 g of rocks and soils. Our nominal stay time is up to 60 days and allows time for either vertical drilling for core samples or operation of a small tethered rover. A small robotic arm is used for sample transfer and for a contingency sample. The rugged lander would have three fixed legs, crushable materials, and a hazard avoidance system. The lander would have small solar arrays and passive thermal control due to the short stay time on the surface. The lander can be launched on a Delta 7925H class vehicle in most opportunities.

ERV design. The Earth Return Vehicle is derived from the Stardust spacecraft. The spacecraft propulsion is monoprop and requires no large main engine. It uses four small 4.5 N thrusters for delta V. The spacecraft is fully redundant, has a fixed solar array, and fixed medium gain antenna. The small Sample Return Capsule and capture hardware is carried on one end of the rectangular box enclosure, just as Stardust carries its SRC. The ERV provides the capability for 1 km/s in delta V. This is sufficient to correct for up to 45 day shifts in the MAV launch. The ERV is targeted to arrive about 15 days after the landing. The MAV could launch anytime between Day 1 and Day 60 and allow for a successful rendezvous. The ERV/SRC can be launched on a Delta 7425 class vehicle. The Mars flyby geometry is shown in Figure 4.

MAV design. The Mars Ascent Vehicle is a two stage rocket with a solid first stage with a gimballed nozzle. The second stage can either be a spin-stabilized solid or an advanced liquid stage. Compared to a MAV intended to inject into a low Mars orbit, the delta-V requirement is about 50% greater, but the injection accuracy's are less stringent since the ERV compensates for the rendezvous and since the launch is directly to zenith and does not require sophisticated guidance.

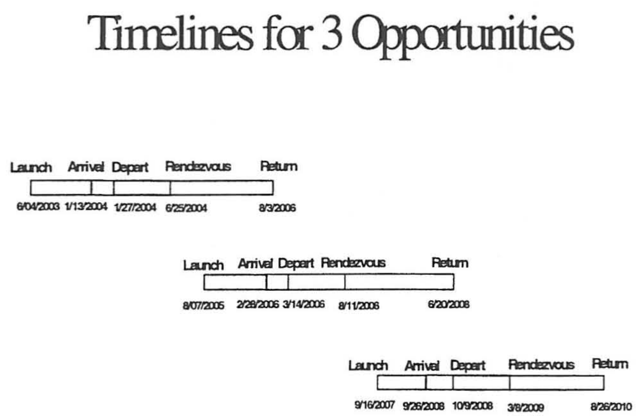
OS design. The solar Orbiting Sphere is derived from the JPL concept for the Mars orbiting sphere but is slightly larger in diameter. The sphere is covered by triple junction GaAs solar cells that operate a beacon. The beacon is enhanced to put out a stronger pulsed UHF signal that can be tracked from Earth.

Rendezvous and Sample Transfer. The ERV is guided to within rendezvous range by Earth-based tracking of both the OS and ERV. Acquisition by optical or beacon methods is simpler than in Mars orbit because there are no occultation's or 3-body orbital dynamics. Proximity operation are especially simplified by posing the rendezvous in a OS-ERV-Earth linear geometry, with constant (no-occultation) telecommunications and full sun illumination. If need be, the final closures and docking could be done in days or even weeks with no impact or complications, compared to the orbital case.

Sample Reentry. After aseptic transfer of the sample using special techniques which eliminate elaborate back-contamination procedures on the surface of Mars, the OS is quarantined inside a cocoon and then placed in a high-integrity vault inside the SRC. Reentry at Earth is performed just as with Stardust, drawing upon already developed and tested designs. The Stardust samples return in early 2006, and the Mars samples would arrive approximately mid-2008.

References::

[1] Author B. M. Sutter (1995) *AAS Spaceflight Mechanics, 95-151,* "Trajectory Optimization of Nodal Re-encounter Martian Transfer Orbits", p 367-375.



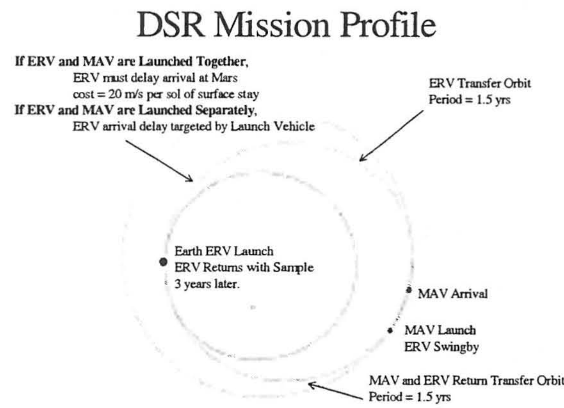


Figure 1

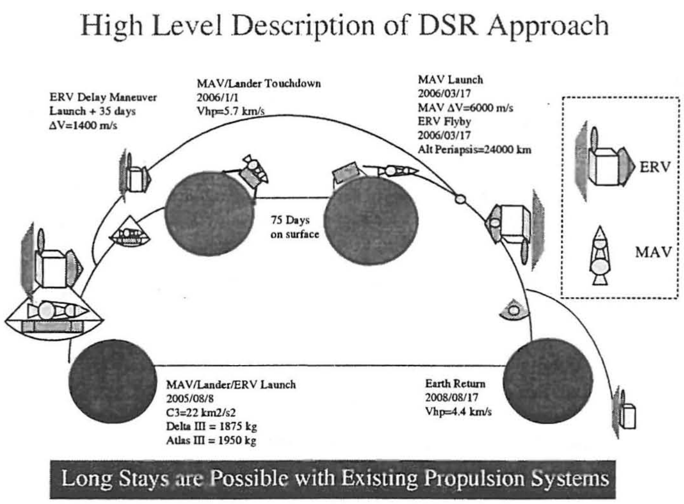
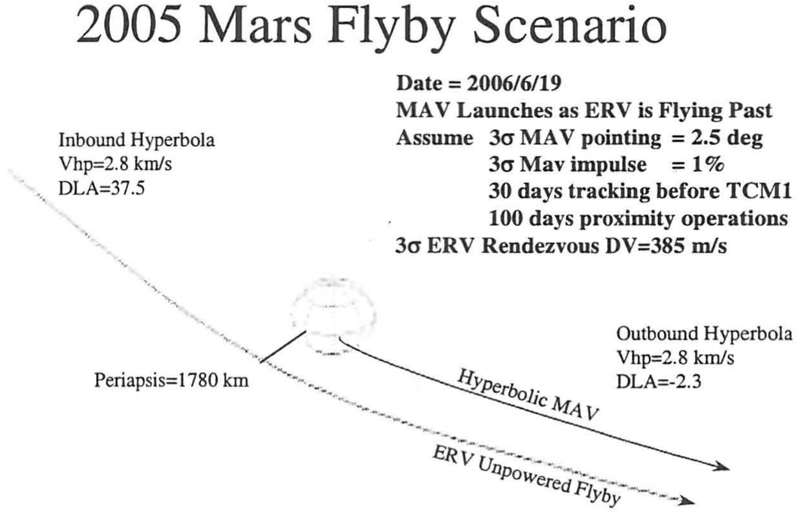


Figure 2



Exobiology Robotics Laboratory to Search for Life on Martian Subsurface Water and Permafrost.

D. C. Gan, L. Kuznetz, D. Chu, V. Chang, M. Yamada, C. Lee and R. Lee.
1637 Franklin Stree, Berkeley, CA 94702, email: dcgan@worldnet.att.net or
640 Woodmont Avenue, Berkeley CA 94708 email: N2Mars@aol.com

Introduction: A conceptual design of a robotics laboratory was constructed to search for life forms in Martian subsurface water and permafrost by cultivation of bacteria by using a variety of media to grow bacteria of the Archea group and Eubacteria. Other growth, morphology, motility and mode of reproduction of bacteria and organisms of the Protista will be observed with microscopy. The entire operations is controlled by a computer.

Methods and Material:

The entire operation is controlled by a computer program and the data derived from the experiments are relayed by telemetry to the Orbiter. The experiment is contingent on accessibility of water from Mars by a digger apparatus or melted permafrost.

First Phase

Water samples are delivered to the receiver intake tube by a pump into a holding and settling tank to allow heavy particulates to settle. Upon command, the sample is pumped through a 1 mm sieve, then 10 mL aliquots are dispensed into 4 receptables to observe for Protista. Then more samples are filtered through a 50 micromL membrane filter and 10 mL aliquots are dispensed into culture vials containing concentrated media by injection through a cap. The drum assembly is rotated by a small motor to allow successive vials containing media of various formulation and to be filled with water samples. Some vials will contain peroxidase or oxidase to neutralize peroxides and superoxides which may be present in the water sample.

Second Phase

When the vials are filled with sample, each vial is viewed with the microscope/video camera system for presence of bacteria or Protista and the data is stored in the memory bank for periodic transmission to the Orbiter.

Third Phase

The experimental program begins at 0 degrees C and the temperature is increased every three days by 5 degrees C increments by means of a small heater. The internal pressure is maintained at 100 millbars helium pressure. After 3 days of incubation, each vial is view by the microscope/video camera system for motility, growth, morphology and mode of reproduction, if any. The Protista cells are also viewed and all data is stored in the memory data bank for transmission to the Orbiter.

Fourth Phase

The experimental program will terminate when 100 degrees C is reached. The cultures are then preserved for further studies or destroyed.

Other Experiments

If feasible, a Chirality Test may be done with paired sets of vials containing media prepared with extro or levo forms of aminio acids and carbohydreate as suggested by Gilbert Levin. Experiment for magnetotactic bacteria.

Discussion:

The Viking experiments were inconclusive to date and this experiment is a direct approach to detect life foms by cultivation and observation in Martain subsurface water and permafrost. Our preliminary experiments on Earth may attempt to culture deep subsurface bacteria such as the newly discovered Bacillus infernus, pseudomonads found in deep ground water and bacteria belonging to Archea. Deep Martian subsurface water may even have nematodes.

References:

(1) Amy, P.S., Haldeman, D.L. "Microbiology of the Terrestrial Deep Subsurface" pp 219-219, Lewis Publishers, CRC (1997)
(2) Carr, Michael "Water on Mars" Oxford Press (1996)
(3) Clifford, S.M. " A Model for the Hydrologic and Climate Behavior of Water on Mars" J. of Geophy. Res. vol 68 (E6) p973 (1993)
(4) Levin, G. (personal communication)
(5) Reid, Joe "The Search for Water", Water World, Amer Water Works Assn April 2000
(6) Jakosky, B "The Search for Life on Other Planets", Cambridge Univ. Press (1998)
(8)Zubrin, R. "The Case for Mars" Simon and Shuster (1997)
(9)Zubrin, R. "Entering Space" Jeremy Tarcher/Putnam, Penquin Books (1999)

Beagle 2 and NASA's Mars 2003 Orbiter: A unique Exobiology Opportunity with an Orbiter.

Everett K. Gibson, Jr.[1], Colin T. Pillinger[2], John Thatcher[3] and Frances Westall[4]. [1]SN2 Planetary Sciences, NASA Johnson Space Center, Houston, TX 77058 (everett.k.gibson1@jsc.nasa.gov). [2]Planetary Sciences Research Institute, The Open University, Milton Keynes MK7 6AA, UK, [3]Astrium, Gunnels Wood Rd., Stevenage SG1 2AS, UK and [4]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058.

With the exploration strategy for Mars undergoing reexamination, the opportunity exists for the incorporation of the 60 kg Beagle 2 lander, developed in the United Kingdon for inclusion on ESA's 2003 Mars Express mission, with NASA's Mars 2003 orbiter derived from the Mars Global Orbiter. The combination of Beagle 2 with a Mars orbiter would result in a unique mission which could obtain information on Mars' life, climate and resources both from orbit as well as on the surface of the planet. Beagle 2 has been developed in the UK for ESA as a low-cost opportunity to study the exobiology of Mars and the spacecraft is in its final stages of manufacture. Only limited modifications to the Beagle 2 package would be required for inclusion on NASA's Mars 2003 orbiter. With the ESA Mars Express mission launch in 2003 and a potential NASA Mars orbiter in 2003, both Beagle 2 landers on Mars would offer a low-cost, decreased risk and increased science return opportunity for the exploration of Mars at two distinct geologically interesting sites.

The combined Beagle 2 and NASA's Mars orbiter mission would include those instruments selected for the orbiter in addition to the 60 kg Beagle 2 lander. The Beagle 2 probe would consist of four components: (1) Entry, descent and landing system (EDLS) derived from concepts proven with Pathfinder, (2) a lander, including scientific instruments, (3) Hold down and release (HRM) and spin up and ejection mechanisms (SUEM), and (4) RF orbiter lander relay system. The latter two components would remain attached to the Mars Orbiter while the descent system and lander would be sent to the surface.

Beagle 2 was developed to search for organic material and other volatiles on and below the surface of Mars in addition to a study of the inorganic chemistry and mineralogy of the landing site [1]. Beagle will utilize a mechanical mole and grinder to obtain samples from below the surface, under rocks and inside rocks. Analysis would include examination of rock and soil samples with an optical microscope, X-ray spectrometery and Mossbauer spectrometery as well as a search for organics and measurement of their isotopic compositions. The Beagle 2 lander has as its focus the goal of establishing whether evidence for life existed in the past on Mars at the site to be visited or at least establishing if the conditions were ever suitable. McKay et al. [2] suggested there was evidence within the ALH84001 meteorite for possible early life on Mars. Gibson et al. [3] presents further evidence for possible biogenic activity within two additional younger martian meteorites.

The heart of the Beagle 2 gas analysis package consists of a mass spectrometer with collectors at fixed masses for precise isotope ratio measurements and voltage scanning for spectral analysis. Samples of surface, subsurface materials and interior rock specimens will be combusted to release organic matter and volatiles. The combustion process will permit detection of all forms and all atoms of carbon present within the samples. A chemical processing system is capable of a variety of conversion reactions including oxidation, reduction and fluorination. Gases are manipulated either by cryogenic or chemical reactions and passed through the vacuum system. There will be two modes of operation: quantitative analysis and precise isotopic measurements. Three main types of study are proposed: (1) search for organic matter, (2) stepped combustion for total light element content and speciation, and (3) atmospheric analysis. Isotopic measurement of H/D, $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{17}O/^{16}O$ and $^{18}O/^{16}O$ along with detection for methane will be carried out. High sensitivity isotopic analysis of the carbon species present within the samples makes no assumptions about the biochemistry on Mars but provides clues to past life as inferred from the isotopic fractionations measured directly on Mars. Isotopic fractionation signatures from biogenic processes survive even in altered rocks. An environmental sensor system for temperature, pressure, wind speed and direction is also included with the lander. The particle radiation environment will be characterized both in terms of rate and dose. The UV flux at the landing site will be measured in a variety of wavelength bands longer than 200nm.

The marriage of an orbiter to remotely measure the global environment of Mars along with a Beagle 2 lander offers a unique opportunity to study the key scientific objectives associated with "following the water" and "quest for life". Such a combined mission is worthy of consideration not only for the 2003 opportunity but for future Mars exploration considerations.

References: [1] M.R. Sims et al. (1999), SPIE Conf. On Instruments, Methods and Missions for Astrobiology II, SPIE Vol. 3755, 10-23. [2] D.S. McKay et al. (1996) Science 273, 924-930. [3] E.K. Gibson et al. (2000) Precambrian Research (in press).

ACOUSTO-OPTIC IMAGING SPECTROMETERS FOR MARS SURFACE SCIENCE. D. A. Glenar[1] and D. L. Blaney[2], [1]Planetary Systems Branch/693, NASA Goddard Space Flight Center, Greenbelt, MD 20771, [2]Jet Propulsion Laboratory, Pasadena, CA, 91109.

Introduction: NASA's long term plan for Mars sample collection and return requires a highly streamlined approach for spectrally characterizing a landing site, documenting the mineralogical make-up of the site and guiding the collections of samples which represent the diversity of the site. Ideally, image data should be acquired at hundreds of VIS and IR wavelengths, in order to separately distinguish numerous anticipated species (see Table 1), using principal component analysis and linear unmixing [1].

Cameras with bore-sighted point spectrometers can acquire spectra of isolated scene elements, but it requires 10^2 to 10^2 successive motions and precise relative pointing knowledge in order to create a single data cube which qualifies as a spectral map. These and other competing science objectives have to be accomplished within very short lander/rover operational lifetime (a few sols). True, 2-D imaging spectroscopy greatly speeds up the data acquisition process, since the spectra of all pixels in the scene are collected at once. This task can be accomplished with cameras that use electronically tunable acousto-optic tunable filters (AOTFs) as the optical tuning element. AOTFs made from TeO_2 are now a mature technology, and operate at wavelengths from near-UV to ~5 μm. Because of incremental improvements in the last few years, present generation devices are rugged, radiation-hard and operate at temperatures down to at least 150K so they can be safely integrated into the ambient temperature optics of in-situ instruments such as planetary or small-body landers. They have been used for ground-based astronomy [2], [3], and were also baselined for the ST-4 Champollion IR comet lander experiment (CIRCLE), prior to cancellation of the ST-4 mission last year.

AIMS (for Acousto-optic Imaging Spectrometer), is a prototype lander instrument which is being built at GSFC with support by the NASA OSS Advanced Technologies and Mission Studies, Mars Instrument Definition and Development Program (MIDP). *AIMS* is capable of tunable spectroscopic imaging of surface mineralogy, ices and dust between 0.5 and 2.4 μm, at a resolving power ($\lambda/\Delta\lambda$) which is typically several hundred [4], [5]. The design spatial resolution, similar to IMP [6] and SSI, will allow mapping at scales down to ~1 cm.

Spectroscopic and Mapping Objectives: Table 1 lists spectral features that would be detected and mapped by *AIMS*. These include the signatures of Fe^{2+} and Fe^{3+} -bearing minerals which are linked to ancient hydrothermal activity, chemically bound and adsorbed H_2O and spectral features which identify and distinguish the grain size of CO_2 and H_2O ice. Positions and shapes of water ice bands will be clearly distinguishable from those due to molecular water and OH^- absorptions in silicate minerals.

Table 1. Survey of Spectral Subjects [7]-[10]

Range (μm)	Mineralogy
0.50 - 0.90	Fe^{3+} electronic features in hematite (α-Fe_2O_3 and nanophase) and goethite (α-FeOOH)
0.75 - 1.00 1.90 - 2.30	Fe^{2+} in ferromagnesium silicates (e.g., Pyroxenes)
1.4, 1.9 2.2-2.4	Structural OH, bound H_2O and metal-OH features in smectite clays
> 1.6	Onset of strong "3 m" hydration feature (negative spectral slope)
	Ices
2.2-2.4	Broad but pronounced features in fine-grained H_2O ice. CO_2/H_2O ice discrimination
~2.3	Narrow CO_2 ice features, grain-size dependent

Operation: The operating characteristics of the instrument are summarized in Table 2 below, and a layout of the optics is shown in Figure 1. The *AIMS* optics module consists of two independent, side-by-side optical channels which tune over VIS/near-IR and short-wave IR bands. As with IMP and SSI, the optical channels are separated by about 15 cm for operation as a stereoscopic imager within the range of tuning overlap (0.85-1.02 μm). The VNIR focal plane, supplied by Lockheed Martin, is a copy of the CCD array built into the Mars Polar Lander SSI. A low dark current, HgCdTe IR detector array built by Rockwell is used in the IR channel. Device dark current measurements and coupled instrument performance modelling show that this FPA will be useable at ambient temperatures up to ~ 260 K. A companion electronics module (not shown) holds all of the instrument "warm" electronics, which includes timing generators, DC-DC converters, programmable RF module for the AOTFs, A-to-D conversion and data co-add memory.

Data Acquisition. Using *AIMS,* a spectrally complete panorama consisting of 60, 200-wavelength image cubes could be acquired in slightly over 3 hours.

At 12-bits/pixel, 3.1 mrad spatial resolution (corresponding to 4x4 pixel binning) and 8x data compression, the size of this entire data set, including the spectral cube of a calibration target, is about 76 Mbits. Autonomous prefiltering of the data, e.g., rejection of low signal to noise images, would typically reduce the data set by an additional 25%, bringing the data burden to 57 Mbits. This should be well within the 1-sol data transmission envelope in future landed missions. One high spatial resolution image at each pointing position could serve as a precise spatial context image.

Table 2. *AIMS* Specifications

Channel	VIS/NIR	IR
Tuning range (μm)-	0.50-1.02	0.85-2.40
Resolution (λ/Δλ)-	210-530	190-450
Camera field-of-view-	12 x 17	12 x 12
Pixel field-of-view-	0.78	0.78
Wavelength selection-	Continuous, using AOTF	
Stereoscopic capability-	YES	
Signal-to-noise-	20 to ~300	
Peak electrical power-	~ 12 W	
Ambient temp range-	170-260 K	
Mass (optics module)	1.9 kg	

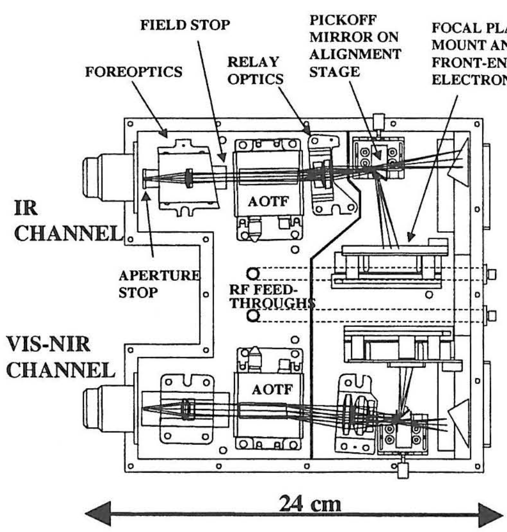


Figure 1. Optics module

Lab Validation: A breadboard of the *AIMS* VNIR channel is being used in the lab to record image cubes of field samples representing some relevant mineralogies. (Similar AOTF demonstrations have also been done by us with aluminous clays at IR wavelengths).

Fig. 2 shows sample spectra of Jarosite and red Hematite from two spatial points in an image cube. The data has been calibrated to absolute reflectance using a large Spectralon (Labsphere) reference plate which forms the backdrop in the image. USGS [11] spectra of powdered reference samples are included for comparison. Under our present schedule, assembly of the optics and electronics modules will be completed by Fall of calendar '00, followed by integration and testing with the instrument in a cold shroud. Field demonstrations (location TBD) are scheduled for Spring of calendar '01.

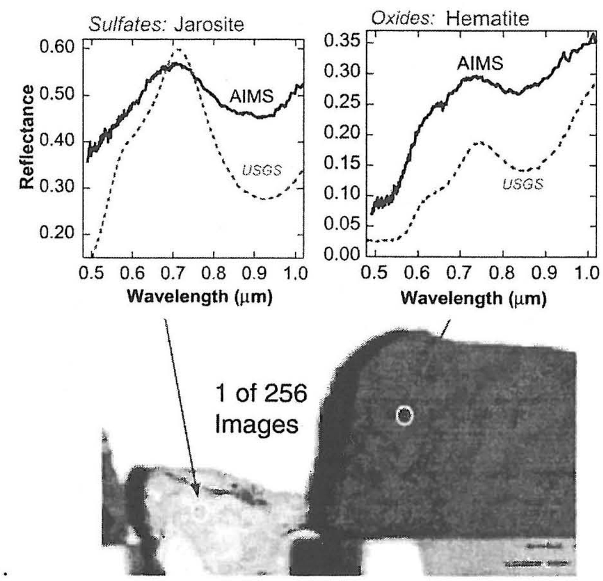


Figure 2. Lab spectra of field samples using the *AIMS* VNIR-channel breadboard

References: [1] Adams J. B. et al. (1993) in *Remote Geochem. Analysis,* Pieters and Englert, Eds., 145-166. [2] Glenar D. A. et al. (1997) *Pub. Astron. Soc. Pac., 109*, 326-337. [3] Chanover N. J. et al. (1998) *JGR, 103*, 31335-31348. [4] Glenar D. A. et al. (2000) LPS XXXI, Abstract 1954. [5] Glenar D. A. et al. (2000) *Fourth IAA Conf. On Low Cost Planetary Missions*, paper IAA-L-1004. [6] Smith, P. H. et al. (1997) *JGR, 102*, 4003-4025. [7] Bishop J. L. and C. M. Pieters (1995) *JGR, 100*, 5369-5379. [8] Clark R. N. (1981) *JGR, 86*, 3087-3096. [9] Bell J. F. et al. (1994) *Icarus, 111*, 106-123. [10] Klassen D. R. et al. (1999) *Icarus, 138*, 36-48. [11] Clark R. N. et al. (1993) USGS Open File Rpt. 93-592.

Acknowledgements: Support for the development of *AIMS* is provided by the NASA Code SM, Mars Instrument Development Program (MIDP).

STRATEGY FOR THE EXPLORATION OF MARS. M. P. Golombek, Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109.

Introduction: This abstract discusses a strategy for the scientific exploration of Mars by reviewing those that have been proposed previously by various science advisory groups. The strategy for exploration is based on first obtaining a global assessment or reconnaissance level of knowledge about Mars before more detailed study of specific locations with large rovers and sample returns. It also suggests a progression of missions and information needed for setting up outposts and ultimately eventual human exploration.

Review of Exploration Strategies: About 10 years ago the NASA appointed Mars Science Working Group prepared "A Strategy for the Scientific Exploration of Mars" [1]. This document was prepared in response to the Space Exploration Initiative [2], which proposed a new roadmap for exploring space. Although the Space Exploration Initiative was never carried out, the report by the Mars Science Working Group [1] stands as the last comprehensive strategy document to review the science objectives and precursor knowledge required for human missions and to propose a strategy for exploring Mars. This document reviews previous COMPLEX [3, 4], Space Science Board [5], and SSEC reports [6, 7, 8] and proposes a strategy for exploring Mars leading up to human exploration. The strategy proposed was reiterated by subsequent COMPLEX [9], SSES [10], OSS [11], and ESA [12] reports until the Mars Surveyor Program was instituted [13].

The exploration strategy suggested [1] involves an initial phase of global assessment in which information is gathered on the distribution of materials, environmental conditions and the geological, biological, and climatological history of the planet (Fig. 1). This reconnaissance phase of exploration included both global remote sensing (obtained by Mars Observer at that time) and a network mission to obtain "ground truth" at a number of sites. This ground truth was intended to provide calibration points for the global remote sensing data in terms of both the chemistry and mineralogy as well as the distribution and type (rocks, soil, sand, etc.) of surface materials. This reconnaissance phase of exploration was followed by a more detailed evaluation of specific locations that appeared scientifically or programmatically interesting. This phase of exploration used site characterization orbiters, rovers and sample returns to obtain detailed information of a smaller number of sites before a site was selected for a robotic outpost or human landing (Fig. 1).

A review of how the recommendations of COMPLEX, SSEC, and SSES have varied through time [1-11] shows that the missions recommended by these science advisory groups generally follow what the engineering community believes is possible within the programmatic environment. From the 1970s through the mid to late 1980s, investigations of local sites and sample returns were stressed over global investigations. With the scientific realization from the study of Viking orbiter data that the climate may have varied with time on Mars and that the early environment may have been different than today's, global scale investigations were emphasized. Sample return missions were effectively abandoned by the early 1990s [e.g., 4, 9] after the results of the Mars Rover Sample Return study showed how expensive this class of missions are and as the programmatic environment stressed less expensive missions. By the mid 1990s the science advisory groups were advocating a global remote sensing mission that was followed by a network mission [9, 10]. By the late 1990s, sample returns were again stressed [11] in response to the putative evidence of life in the Mars meteorite Alan Hills 84001. The recent loss of the Surveyor missions in '98 and technical and cost studies of sample return missions have resulted in a re-evaluation of the Mars Exploration Program. As was the case for previous changes in the recommendation of these advisory groups, there have been few changes to the important scientific questions and objectives for Mars; what has changed has been the relative emphasis of certain kinds of science and the programmatic environment.

Exploration Strategy: There are many advantages to performing a phase of truly global reconnaissance before committing to the detailed exploration of particular locations as outlined by the Mars Science Working Group [1]. At the most general level, obtaining information to answer general questions prior to obtaining information to answer very specific questions yields a logical progression of knowledge about a planet. What rock types make up the crust of Mars? What are the 100 or so morphologic/geologic units mapped from the Viking images? What is the internal structure of the planet? Is it still geologically active? What is the climate on Mars and how does it vary with time? These are all basic questions that need to be addressed along with the specific questions that drive the program (life, climate and resources). In fact it can be argued that trying to answer the questions that drive the program without also addressing other fundamental aspects of Mars produces a less balanced flow of information that could lead to erroneous conclusions.

Global reconnaissance involves both global remote sensing as well as obtaining "ground truth" for calibrating that remote sensing data. Just as a field geologist might begin interpreting airphotos before mapping an area, he or she would certainly go into the field to check those interpretations before actually carrying out detailed field mapping. This phase of ground truth should not be limited to near equatorial latitudes, but should investigate the planet from pole to pole. The importance of obtaining ground truth information from the higher latitudes is particularly important for future human exploration. Landing sites and outposts for human missions likely will be driven by the availability of resources, such as water, which may be more prevalent at higher latitudes. The exploration of higher latitudes is thus equally important to the study of life, climate, and resources.

Performing this phase of global reconnaissance before selecting sites for more detailed study will allow the return of samples to Earth better suited to addressing the program goals than if a sample return site were selected without this information. In particular, obtaining multiple ground truth sites will allow a much better understanding of the diversity of materials available on Mars. Selecting a landing site with this information will result in a site and samples much better suited to addressing the objectives of the program (life, climate and resources). Without the ground truth, there will be substantially more uncertainty in the interpretation of what is actually at the landing site than if the remote sensing had many calibration points.

The global reconnaissance phase of exploration can be accomplished in a number of ways; generally, orbital remote sensing missions followed by ground truth at a large number of locations or network missions are considered. This reconnaissance phase of exploration would be followed by the detailed study of locations by rovers where the most important scientific questions can be addressed, including the return of samples from these locations.

References: [1] Mars Science Working Group (1991) *A Strategy for the Scientific Exploration of Mars*, JPL Doc. D-8211, 45pp. [2] Synthesis Group (1991) *America at the Threshold, America's Space Exploration Initiative*, U. S. Gov. Print. Off., Wash. D. C., 114 pp. [3] COMPLEX (1978) *Strategy for Exploration of the Inner Planets: 1977-1987* National Academy of Sciences, Wash. D.C., 97 pp. [4] COMPLEX (1990) *1990 Update to Strategy for Exploration of the Inner Planets* National Academy Sciences, Wash. D.C., 47 pp. [5] Space Science Board (1988) *Space Science in the Twenty-First Century: Planetary and Lunar Exploration* National Academy Sciences, Wash. D.C., 111 pp. [6] SSEC (1983) *Planetary Exploration through year 2000: A Core Program* U. S. Gov. Print. Off., Wash. D. C., 167 pp. [7] SSEC (1986) *Planetary Exploration through year 2000: An Augmented Program* U. S. Gov. Print. Off., Wash. D. C., 239 pp. [8] SSEC (1988) *Planetary Exploration through the year 2000: Scientific Rationale* U. S. Gov. Print. Off., Wash. D. C., 88 pp. [9] COMPLEX (1994) *An Integrated Strategy for the Planetary Sciences: 1995-2010*, National Academy Sciences, Wash. D.C [10] SSES (1994) *Solar System Exploration 1995-2000, Office of Space Science, Strategic Plan, 1994 Space Science for the 21st Century*, U. S. Gov. Print. Off., Wash. D. C. [11] Space Science Enterprise Strategic Plan (1997) *NASA Origins, Evolution and Destiny of the Cosmos and Life*, U. S. Gov. Print. Off., Wash. D. C. [12] ESA (1990) *Mission to Mars, Report of the Mars Exploration Study Team*, ESA SP-1117, ESTEC, Noordwijk, 138 pp. [13] McCleese, D. J., et al., (1994) *Mars Surveyor Science Objectives and Measurements Requirements Workshop*, JPL Tech. Rep. No. D12017, 181 pp.

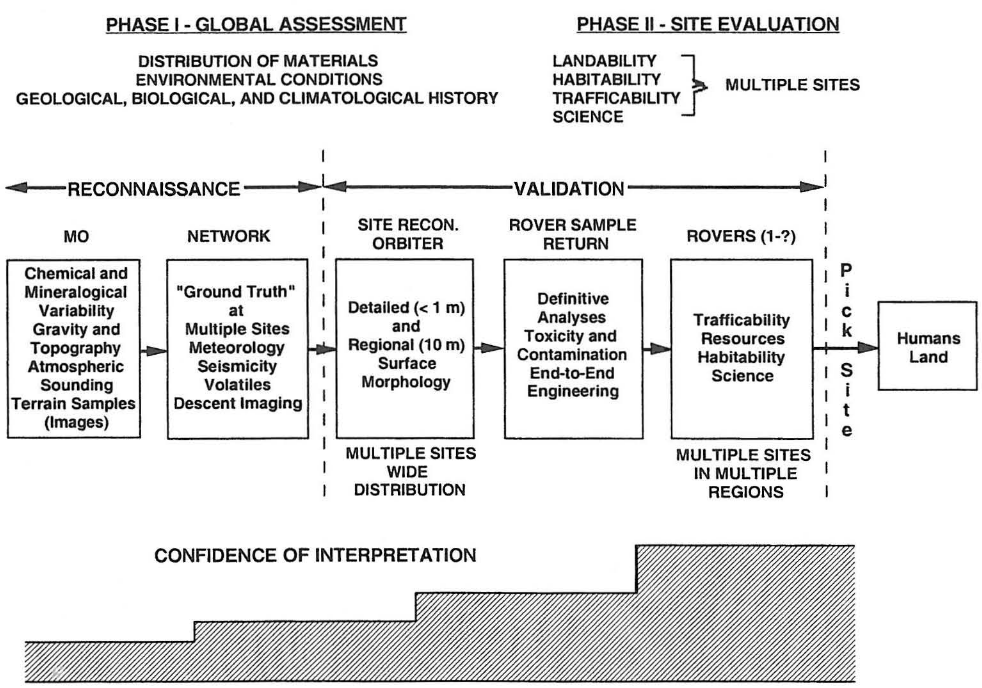
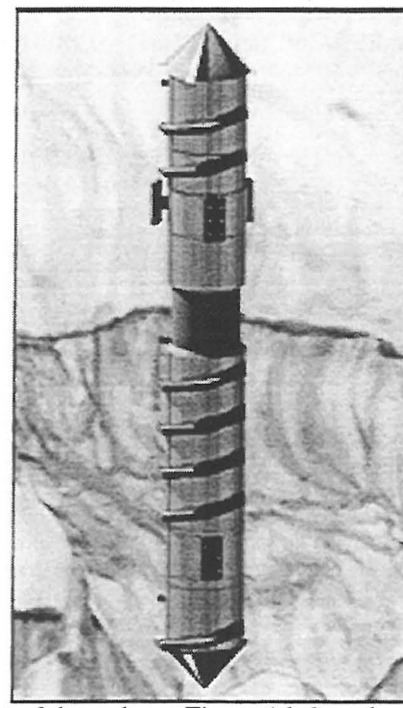


Figure 1. Scientific strategy for the exploration of Mars suggested by the Mars Science Working Group [1].

AN INCHWORM DEEP DRILLING SYSTEM FOR KILOMETER SCALE SUBSURFACE EXPLORATION OF MARS (IDDS). S. P. Gorevan, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, gorevan@hbrobotics.com), K. Y. Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), T. M. Myrick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, myrick@hbrobotics.com), P. W. Bartlett, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, bartlett@hbrobotics.com), S. Singh, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sase@hbrobotics.com), S. Stroescu, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sergiu@hbrobotics.com), Roopnarine, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, roop@hbrobotics.com), S. Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com)

Introduction: The Inchworm Deep Drilling System (IDDS) is a compact subsurface transport system capable of accessing regions deep below the surface of Mars. The concept is being developed at Honeybee Robotics to enable future subsurface science missions at depths on the order of one kilometer. The IDDS gets around the problems posed by tethers or umbilicals through the employment of drilling techniques that require no more power than that offered by a radioisotopic thermoelectric generator (RTG). The IDDS we propose requires no tether or umbilical of any kind. The tether free, self-powered and self-propelling device will be capable of burrowing to a specified depth and retrieving samples or of transporting instruments along with it for in-situ analysis. The IDDS also would be well suited for reaching greater depths on Mars or for subsurface exploration of Europa. The device's unique, inchworm-burrowing method appears capable of achieving the near-term depth requirement of one kilometer. In addition, it is foreseeable that the IDDS will be capable of autonomously drilling through soil, ice and rock down to tens of kilometers below the surface. Once deployed by a lander on the martian surface, the IDDS autonomously drills into the ground under it's own power. The inchworm motion of the device's two segments both walks it forward and provides the thrust necessary for drilling. Feet on each segment grip the walls of the hole. Flights along the body pass cuttings to the rear. Sampling and analysis take place once the proper depth is achieved, and since the burrowing method is independent of gravity, the IDDS can then return to the surface.

The Basic IDDS Conceptual Framework: The IDDS is largely a convergence of concepts from two previous devices designed and produced by Honeybee Robotics. The planetary surface burrowing mole concept extends our work on a tethered subsurface sampler effort conducted in 1993 for Dr. Paul Mahaffy at NASA GSFC [1]. And the inchworm burrowing method is a direct application of our work on the Welding & Inspection Steam Operations Robot (WISOR), a steam tunnel-walking robot provided for the Consolidated Edison Corp. of New York. The IDDS robot is between 10 and 15 centimeters in diameter and 1 meter in length. Two symmetrical segments comprise the IDDS, each with a drill bit



and a set of three shoes. Figure 1 below shows a rendering of the concept.

Figure 1: CAD Rendering of the IDDS concept

Power: As mentioned above, the IDDS utilizes a single RTG for electrical power. The high reliability, power density and output duration of RTGs state a strong case for their use in a kilometer-deep burrowing device. The IDDS dimensions are a practical forecast based on the current trend in RTG development.

Surface Deployment: The IDDS deploys at the surface in a similar method to the mole mentioned above that was developed for NASA GSFC. A cylindrical tube houses the IDDS while on the lander and the tube is positioned at the surface. To begin the burrowing process, the IDDS grips the inner walls of the tube and extends forward, into the soil. The IDDS continues to walk forward, eventually exiting the deployment tube and gripping only the walls of the hole it is creating.

Burrowing Method: The inchworm analogy that the IDDS employs allows it to burrow through soil independent of the magnitude or direction of gravity. A linear actuator connecting the aft segment to the fore segment of the IDDS contracts and expands the robot in length. Standard motors drive the fore and aft drill bits as well as each of the six feet (three fore and three aft). Thrust and torque for drilling and thrust for sliding the robot forward are achieved by anchoring the feet into the walls of the hole created. A similar method propels Honeybee Robotics' previous device, WISOR, mentioned above. WISOR walks through steam tunnels using two attached segments, each with feet that grip the inner walls of the pipe. Figure 2 shows one of the segments with its feet extended.

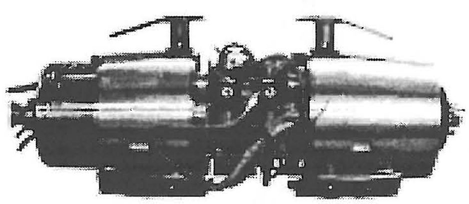


Figure 2: One segment of the Welding & Inspection Steam Operations Robot (WISOR)

Figure 3 below shows the stages of the IDDS burrowing process, beginning with step 1 on the left and continuing through to step 6 on the right. The figure demonstrates the walking cycle, which begins again in step 5.

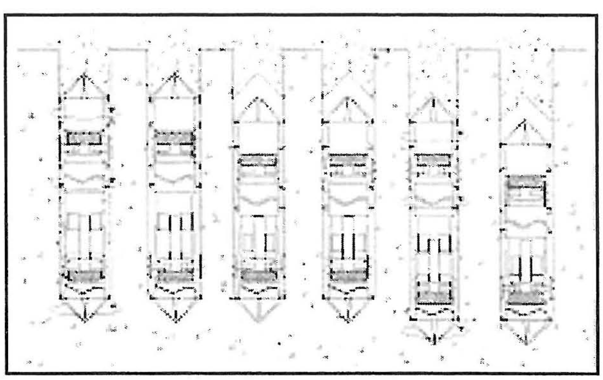


Figure 3: Schematic of the IDDS penetration process

Each of the six steps shown in Figure 3 is detailed below:

Step 1. The shoes on the aft section push into the borehole walls while the forward section extends forward slowly while spinning the forward drill bit, drilling deeper.

Step 2. The forward section shoes push into the borehole walls and the aft section shoes disengage.

Step 3. The IDDS contracts, pulling the aft section forward.

Step 4. The aft section shoes engage and the forward section shoes disengage.

Step 5. The cycle begins again as the IDDS extends while spinning the forward drill bit, drilling further.

Step 6. After engaging the forward shoes and disengaging the aft shoes, the IDDS contracts, pulling the aft section forward.

Drilling: Honeybee Robotics' extensive drill bit development for the Mini-Corer, a part of the Athena investigation, readily applies to the IDDS. The design of the IDDS drill bits will likely benefit from the company's present work in conjunction with DeBeers on both natural diamond and manufactured, polycrystalline diamond cutting teeth. Once the cutting teeth dislodge material and push it past the bits, rotating helical flights direct the cuttings along the body and to the rear of the robot. Since the cuttings would pack only loosely behind the robot, it is necessary for it to add a step in the burrowing process. This step consists of extending the rear section backward to compact the loose, freshly produced cuttings before moving on to a greater depth.

Accommodating Scientific Functions: Once the IDDS burrows to the depth specified, it can perform in-situ analysis as well as sample acquisition. With data and samples stored on board, the IDDS can reverse its burrowing process and return to the surface. Various in-situ observations and tests can be facilitated by the IDDS such as imaging and spectroscopy. Once samples are brought into the IDDS by the sample acquisition hardware, treatment of the samples such as baking for a GCMS would be feasible as well. Sample acquisition could consist of collecting loose cuttings or with the use of a Mini-Corer-type device, solid core samples. Sealed compartments contain the samples for their return to the surface.

References: [1] "A Tethered Subsurface Sample Acquisition System" performed for NASA Goddard Space Flight Center #NAS5-30894. Period of performance: April-November 1993.

MARS AEROBOT MISSIONS. R. Greeley[1], J.A. Cutts[2], R. Arvidson[3], J. Blamont[4], D.L. Blaney[2], J. Cameron[2], V. Kerzhanovich[2], I.S. Smith[5] and A. Yavrouian[2], [1]Dept. Of Geology, Ariz. State Univ., Box 871404, Tempe, AZ 85287-1404, Greeley@asu.edu, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [3]Dept. of Geosciences, Washington Univ., St. Louis, MO, [4]Center for Nat'l d'Etudes Spatiales, Paris, France, [5]Wallops Flight Facility, Goddard Space Flight Center, MD.

Overview: Mars aerobots constitute a class of mission nearly a factor of 10 smaller than earlier concepts for Mars balloons. A key goal is to achieve high payload mass fraction in a small total systems mass and to maximize the scientific potential of that payload.

The "low and slow" attributes of aerobot flight paths afford advantages for many observations and measurements of Mars. Scientific objectives include surveys of remnant magnetism, studies of the surface with high resolution stereo imaging, and investigations of the structure and dynamics of the atmosphere with an in situ meteorology payload.

Mission Description: The balloon system could be delivered to Mars as a mission in which the balloon would be deployed by parachute from the aeroshell at an altitude of about 7 km on Mars and inflated over the course of a few minutes as the parachute descends. During the ensuing mission, which may range in duration from a few days to several weeks, the balloon and its payload would circumnavigate the planet at least once. Data will be transmitted to a Mars orbiter and relayed to Earth.

Technologies: The mission would use capabilities developed in ongoing technology development programs and ground based aerobot technology validation activities, including:

1. Technologies for Ultra Long Duration Balloons (ULDB) for Earth's stratosphere developed with NASA Code S support by the NASA GSFC Wallops Flight Facility will be incorporated through an ongoing JPL/GSFC collaborative activity

2. Ground based validation of deployment and inflation and superpressure balloon technologies for a Mars Aerobot Technology Experiment conducted in the Mars Aerobot Validation program (MABVAP) program. This program, the subject of a companion paper, validates those key technologies that can be tested in the Earth's environment.

3. Technologies for miniaturized sensors, space computers and low temperature survivable power systems that have been developed in the Mars Exploration Program, in New Millennium DS-2 and in MUSES C.

4. Technologies for autonomous position determination and path prediction and modeling and simulation developed at JPL.

Science Observations: From its vantage in the atmosphere and by traversing several tens of thousands of kilometers over the surface of Mars, Mars aerobots would make key surface observations and acquire atmospheric measurements.

Surface Observations: The surface observations would include:

1. Unique observations of remnant magnetic in the Martian surface using a microminiaturized magnetometer. Remnant magnetism was discovered on Mars in late 1997 by the Mars Surveyor orbiter. The Mars aerobot measurements will be at much higher resolution and exploit the low altitude(<5km) and the long ground-track profile (>10,000km) of the aerobot and cannot be replicated by either orbital or surface platforms. Objections include searchers for remnant magnetism and polar renewal, as might be exhibited in lava flows in the northern plains.

2. High resolution stereo imaging observations of features beneath the ground track with 10 times higher resolution than is feasible from orbit. These measurements will be used to identify potential habitats where evidence of past life can be found and to characterize hazards on the surface that would be encountered for future lander and sample return missions.

3. Electromagnetic sounding of the subsurface at low frequencies to characterize the stratigraphy and search for evidence of water in the subsurface layers.

Atmospheric Observations: The Mars Aerobot Mission will measure pressure, temperature and cloud properties. These measurements will be used to characterize:

1. fluctuations in air mass properties such as temperature, water vapor concentration, vertical velocity, cloud and dust particle properties) and radiation field properties on meter length scales and 10-to-100 second time scales.

2. temporal correlations among measured fields which are diagnostic of atmospheric waves, convection, and other small-scale phenomena.

3. diurnal changes in the atmosphere containing key information about how local energy transport mechanisms change with time-of-day

4. Balloon trajectory will provide in situ data on general circulation of the atmosphere

COMPACT ELECTROMAGNETIC EXPLORATION FOR WATER ON MARS USING NATURAL SOURCES R.E. Grimm, Blackhawk Geometrics, Inc., 301 B Commercial Rd., Golden, CO, 80401, and University of Colorado-LASP, Boulder, CO, 80309, grimm@blackhawkgeo.com.

Introduction: Subsurface saline water is a near-ideal low-frequency EM exploration target due to its high electrical conductivity. For liquid water at depths up to several km on Mars, frequencies of 10 Hz to 1 kHz are highly diagnostic of the depth to this conductor. Both lower and higher frequencies contain information about the presence and depth to water, but require independent conductivity estimates. The dielectric-relaxation signature of ice at 1-10 kHz is subtle. Abundant natural EM sources probably exist for Mars, obviating the need for transmitters. These include solar heating of the ionosphere, interaction of the solar wind, ionosphere, and crustal magnetism, and lightning. Surface measurements can be made at multiple locations with magnetometers only, or at a single location by recording both the electric and magnetic fields. A new generation of solid-state magnetometers and high-impedance antennae can provide these measurements compactly.

Method: Radar has been considered to be the most likely tool for detecting subsurface water and ice on Mars. While high-frequency, EM-wave methods offer high resolution and controllable sources from efficient transmitters, they suffer from strong losses in heterogeneous environments. The ESA Mars Express radar could loose 1-100 dB/km 1-way from regolith scattering and ~10 dB/km 1-way from the reflective attenuation of ubiquitous 10-m scale layering on Mars. Low-frequency inductive methods are well-established in exploration geophysics and are particularly well suited to identifying subsurface conductors. Natural EM signals are commonly used for deep sounding. The impedance at any frequency can be derived from the ratio of electric to magnetic fields (magnetotelluric method) or by the spatial gradient of the magnetic field (magnetic-variation method; success of ESA's Netlander likely limited by network geometry). The impedance in turn is usually expressed as an apparent resistivity (reciprocal of conductivity). The apparent resistivity as a function of frequency is used to solve for true resistivity as a function of depth, using the increasing penetration (skin depth) with lower frequency.

In order to explore the basic constraints on inductive exploration, I adopt the classical 1-D impedance formulation for a layered earth [1,2]. The electrical conductivity and dielectric permittivity of water and ice are taken to behave as ideal Debye oscillators [3,4,5]. The electrical properties of rock are modeled after altered basalt, with constant permittivity and conductivity varying exponentially with temperature [3]. The composite properties of water in rock follow Archie's Law [3] using a salinity of 10^4 mg/L. Ice/rock mixing was computed as simple volume average.

Model: The basic model consists of a dessicated zone to 250 m, permafrost to 6 km, a drained zone to 7 km, and liquid water below [6]. Surface porosity is 20% and decays exponentially with depth [6], and the thermal gradient is 10 K/km. Basement is arbitrarily set at 10 km, with a constant conductivity below.

The sounding curves depend strongly on the presence of liquid water (Fig. 1). With no water or ice, the apparent resistivity is large and constant, as most of the spectrum penetrates to the basement. The falloff above 100 Hz is due to the transition from induction to propagation in this very resistive section. The presence of a permafrost zone does little to change this response; the ice is very resistive and the only signature is a slight variation at 1-10 kHz due to dielectric relaxation.

When water is present, the apparent resistivity at the lowest frequencies varies inversely with frequency, which is an indication of looking from a conductor into a resistor ("S-line"), here from the entire regolith (part of which contains water) into the basement. If only this part of the spectrum can be measured, the conductance (thickness-conductivity product) of the overburden can be derived, and hence the depth to the bottom of the aquifer can be inferred for an assumed overburden conductivity. Alternatively, the volume of water could be estimated from the conductivity using an assumed regolith model.

Of greater importance is the portion of the curve showing a positive slope in the range 10-1000 Hz. This is diagnostic of looking from a resistor into a conductor ("h-line"), and uniquely gives the depth to conductive water below the resistive cryosphere.

Frequencies above several kHz are dominated by dielectric (propagative) effects of wave interference; the peak at ~10 kHz is the fundamental mode for the water-table-to-planetary-surface waveguide. Like the low-frequency S-line, this yields the depth of water (now to the top instead of the bottom) for an assumed conductivity, here of the megaregolith above the water table.

Natural EM Sources: Natural sources for EM measurements on Earth include the diurnal ionospheric current and harmonics, lightning and associated ionospheric-cavity modes, magnetic substorms, and MHD waves or pulsations. On Mars, ionospheric heating may be a significant ultra low-frequency source; furthermore, the time-varying effect of the interaction of the solar wind and ionosphere is likely strong. The absence of an extended magnetosphere for Mars indicates that large-scale pulsations and substorms probably do not exist. However, strong, localized, crustal magnetic fields [7] may couple with the ionosphere and solar wind. As the frequency of oscillations is proportional to the magnetic field and inversely proportional to field-line length, we can expect that the locally stronger, more spatially compact permanent crustal fields will give rise to higher-frequency waves than Earth. Of greatest use to EM sounding at depths of hundreds of meters to kilometers would be martian lightning: terrestrial "spherics" provide long-range, broadband signals from 1 Hz to >10 kHz under favorable conditions. Even modest martian dust devils can become sufficiently electrically charged such that the EM discharge, wave-guided by the ionosphere, could be detectable at distances of hundreds kilometers or more [8]. Indeed, if these signals are strong enough, it may be possible to measure the thickness of the ionosphere-to-water-table waveguide directly from the frequency of trapped spherics in the kHz range. Noise (unwanted signal) is likely generated by movement of electrically charged and magnetic dust [9].

Instruments: Vector magnetic fields are usefully measured by fluxgate magnetometers or induction coils. While robustly used in space exploration, fluxgates lack the bandwidth to test the entire spectrum discussed here for natural signals. Induction coils are most commonly used for terrestrial EM studies but are large and heavy. Magnetoresistance is a promising recent method for measuring broadband vector fields: these solid-state devices are under heavy development by the computer industry for disk read-write heads and for nonvolatile, instant-on memory. We are developing an instrument for geophysical applications that exploits spin-dependent tunneling (SDT), the newest magnetoresistive property. The sensor consists of thin films of ferromagnets separated by insulating barriers. When a voltage is applied across the stack, the efficiency of electron quantum-mechanical tunneling (i.e., the current) increases as an external magnetic field rotates the ferromagnets into alignment. The response has been characterized from ~1 mHz to nearly 1 MHZ.
Present performance is limited by 1/f noise introduced by imperfections in the ferromagnet-barrier interface. When this is overcome by improved fabrication methods, we expect a sensor of several grams and several milliwatts per axis with unprecedented bandwidth. Although the final predicted performance is not likely to exceed conventional fluxgates and coils, the tiny SDT will outperform these instruments scaled to the same mass, and thus be especially useful for surface-network, aircraft, or orbiting-constellation missions that have extreme limitations on instrument size and mass.

Electric-field measurements (necessary only for single-station soundings) also pose new challenges. Due to the anticipated very high resistivity of the martian regolith, standard electrodes will not make useful galvanic contact (this rules out conventional DC or IP resistivity investigations as well). Instead, we are developing a shielded electrode that automatically adjusts between capacitative (antenna-like) and galvanic coupling depending on the contact impedance.

This work was supported by the NASA Planetary Instrument Definition and Development Program.

References: [1] Wait J. (1970) *EM Waves in Stratified Media*, Pergamon. [2] McNeill, J. and Labson V. (1988) in *EM Meth. in Appl. Geophys. Vol. 2,* Soc. Explor. Geophys., p. 521. [3] Keller, G. (1988) in *EM Meth. in Appl. Geophys. Vol. 1,* Soc. Explor. Geophys., p. 13. [4] Olhoeft G. (1998) *GPR 98: 7th Intl. Conf. GPR*, Univ. Kansas, 177. [5] Chyba, C. (1998) *Icarus 134*, 292. [6] Clifford, S., *JGR, 98*, 10973. [7] Acuña et al., *Science, 284*, 790. [8] Farrell, W. et al. (1999) *JGR*. [9] Olhoeft G. (1998) *GPR 98: 7th Intl. Conf. GPR*, Univ. Kansas, 387.

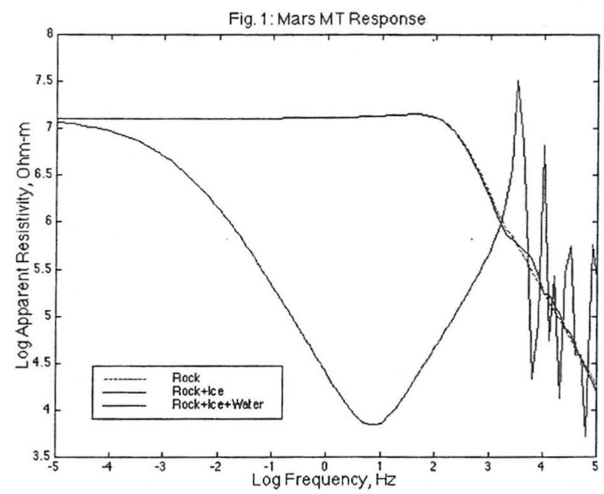


Fig. 1. Apparent resistivity vs. frequency for Mars; see text for model and discussion.

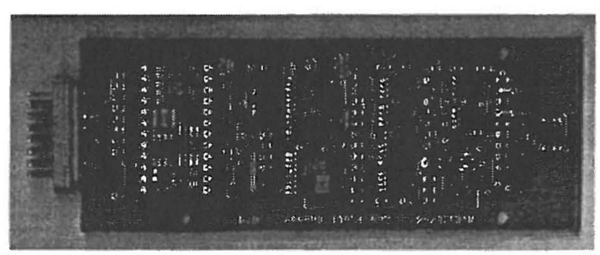


Fig. 2. Breadboard prototype magnetoresistive magnetometer, approx. half scale. Sensor is single chip at right; supporting electronics (preamp, A/D, microcontroller) can eventually be packaged in chip.

MINIATURE CONE PENETROMETER FOR *IN SITU* CHARACTERIZATION AND SAMPLING OF THE MARTIAN SUBSURFACE. J. W. Haas and J. D. Shinn, Applied Research Associates, 415 Waterman Rd., S. Royalton, VT 05068 (jhaas@ara.com).

Over the past decade, cone penetrometer technology (CPT) has emerged as one of the most useful and efficient instruments for characterizing, both physically and chemically, the terrestrial subsurface. The penetrometer consists of a cylindrical rod string, terminated in a solid conical tip that can be dynamically or quasi-statically driven into the ground to depths of up to 200 feet. It is a nearly ideal platform for *in situ* sensor deployment and has been widely employed by geologists and engineers to study the geophysical properties of soils in support of construction projects. The technique is also used in hazardous waste site investigations to determine soil properties and stratigraphy, as well as delineate subsurface chemical contaminant plumes and collect soil samples.

In the course of its development, CPT has demonstrated many distinct cost and technical advantages over competing methodologies. For example, CPT provides a **continuous, *in situ* profile** of subsurface parameters vs. depth during a penetration. Integrating *in situ* analyzers into rotating, cutting drills and augers is exceedingly difficult. It can also collect soil cores with minimal sample disturbance as well as to emplace long-term monitoring sensors (e.g., seismic accelerometers) and sampling tubes (wells) into the subsurface - all of which have been proposed as part of future missions to Mars.

A logical extension of CPT is to exploration below the Martian surface. We believe subsurface investigation is an important next step in exploring Mars because, as on earth, most of the "keys to the past" are likely to be found underground, protected from surface weathering. Furthermore, understanding subsurface geophysical properties will also be important to successful landing of larger spacecraft, travel and construction during later human missions to the planet. Application of CPT to Mars exploration would be relatively low-risk, taking practical advantage of considerable previous investment in state-of-the-art deployment, sampling and sensing technologies. For example, nearly every one of the dozens of sensors already developed for terrestrial CPT would find a similar use on Mars. A representative list of CPT sensors and their potential application to Mars exploration is presented in Table 1. It is notable that many of these sensors have already been employed or are proposed for Martian surface investigations.

Terrestrial CPT systems are large and heavy. The keys to adapting CPT for near-term planetary exploration are to downsize the equipment, develop an alternative to the hydraulic "push" system, and reduce overall power requirements. Under a first project funded by NASA, we have established feasibility in each of these areas and designed a miniature CPT system for planetary exploration. The mini-CPT consists of small-diameter sampling and characterization probes and a unique static-impact probe deployment system that requires < 10 W electrical power and < 2.5 kg impact mass. A characterization probe that can view and measure subsurface soil particles, collect soil gases, measure temperature, classify soil type (sand, clay, etc.), and measure soil moisture (ice) content in real-time has also been designed. The miniature CPT is a versatile platform that will enable new sensor and sampling probes to be quickly integrated and deployed in support of specific Mars exploration objectives as they evolve over the next 15 years.

Table 1. Some CPT Sensors Applicable to the Exploration of Mars

Sensor	Description
Tip & sleeve load	Tip and sleeve loads are measured with strain gauges. Tip-to-sleeve stress ratio is used to classify soil type and strength.
Soil moisture-resistivity	Detects electrical contrast between geologic materials. Can be used to locate mineral deposits, organic strata and water (ice).
Seismic	Used to determine soil damping characteristics, natural seismic activity, etc.
Temperature	Provides equilibrium soil temperatures.
Redox	Measures subsurface oxidation-reduction potential in support of geochemical investigations.
Luminescence	Detects aromatic hydrocarbons and other organic/inorganic luminophores through a sapphire window.
Raman spectroscopy	Performs *in situ* mineralogical analysis with a fiber optic probe. Also identifies high concentration organics in soil.
Video	Video camera provides a real-time view of subsurface soil. Soil color as well as particle size, shape, angularity, and texture can be determined.
XRF, LIBS	Measure soil elemental composition using Sojourner-type XRF or laser induced plasma emission spectroscopy.
Fast GC	A mini-GC detects vapors generated by a unique heated soil vapor sampler.

THE PASCAL DISCOVERY MISSION: A MARS CLIMATE NETWORK MISSION. R.M. Haberle[1], D.C. Catling[2], E. Chassefiere[3], F. Forget[3], F. Hourdin[3], C.B. Leovy[4], J. Magalhaes[5], J. Mihalov[1], J.P. Pommereau[6], J.R. Murphy[7], T. Schofield[8], P. Smith[9], R. Twiggs[10], [1]NASA/Ames Research Center, Moffett Field, CA, [1]SETI Institute, Mt. View, CA, [2]Laboratoire de Meteorologie du CNRS, Paris, [4]University of Washington, Seattle, WA, [5]San Jose State University, San Jose, CA, [6]Service de 'Aeronomie, IPSL, Paris, [7]New Mexico State University, Las Cruces, NM, [8]JPL, Pasadena, CA, [9]University of Arizona, Tuscon, AZ, [10]Stanford University, Palo Alto, CA

The climate of Mars is a major focus of Mars exploration. With the loss of MCO, however, it remains uncertain how it will be achieved. We argue that a truly dedicated climate mission to Mars should have both orbital and landed components, and that these should operate simultaneously for at least 1 Mars year if not longer.

Pascal is Discovery mission that emphasizes the landed component. Its principal goal is to establish a network of 24 small weather stations on the surface of Mars that will operate for 2 Mars years, with an extended mission option for an additional 8 Mars years bringing the total mission lifetime up to 10 Mars years. The stations will collect hourly measurements of pressure, temperature, and optical depth. After delivering the probes to Mars, Pascal's carrier spacecraft will go into an elliptical orbit which will serve as a relay for the landers, and a platform for synoptic imaging. These simultaneous measurements from the surface and from orbit will allow us to characterize the planet's general circulation and its interaction with the dust, water, and CO_2 cycles.

During entry, descent, and landing, each of Pascal's 24 probes will also measure the temperature structure of the atmosphere and acquire images of the surface. These data will allow us to determine the global structure of the atmosphere between 15 and 130 km, and characterize the local terrain to help interpret the landed data. The descent images are part of Pascal's outreach program, as the probe camera system will be developed by faculty-supervised student project. The intent is to generate enthusiasm for the Pascal mission by directly involving students.

Pascal will be launched on a Delta II-7925 in August of 2005. A type I trajectory will deliver Pascal to Mars in January of 2006. On approach, the three-axis stabilized carrier spacecraft will spring deploy the Pascal probes in 4 separate salvo's of 6 each. Global coverage is achieved with small time-of-arrival adjustments in between each salvo. Pascal's probes utilize an aeroshell, parachute, and crushable material for entry, descent and landing. On the surface, their long life and global coverage is enabled by a Micro Thermal Power Source with demonstrated heritage. After all probes are released, the carrier spacecraft will execute a small burn for insertion into an elliptical orbit.

The long lifetime of the Pascal network was chosen in part to maximize the chances that orbital sounding, like that planned with MCO, would occur at some point during the mission. If Pascal is selected for launch in '05, this could occur if MCO-like science is reflown in the '05 opportunity or, if it is reflown in '03, the mission is extended to overlap with Pascal. The combination of temperature sounding from orbit, and surface pressure mapping from the surface will allow a direct determination of the full 3-D wind field for the first time.

Beagle 2

D S Hall (British National Space Centre), C T Pillinger (Open University), M R Sims, D Pullan, S Whitehead (University of Leicester), J Thatcher, J Clemmet (Astrium), S Linguard, J Underwood (Martin-Baker), L Richter (DLR)

Beagle 2 is the British-led lander of the ESA Mars Express mission. The prime objectives of Beagle 2 are to (1) search for criteria relating topast life on Mars, (2) seek trace atmospheric species indicative of extant life, (3) measure the detailed atmospheric composition to establish the geological history of the planet and to document the processes involved in seasonal climatic changes or diurnal cycling, (4) investigate the oxidative state of the Martian surface, rock interiors and beneath boulders, (5) examine the geological nature of the rocks, their chemistry, mineralogy, petrology and age, (6) characterise the geomorphology of the landing site, and (7) appraise the environmental conditions including temperature, pressure, wind speed, UV flux, etc. The entry system comprises a front shield/aeroshell, a back cover/bioshield and release mechanisms. The descent system depends on a mortar, pilot chute, main parachute and main parachute release mechanism. The Lander itself has a clam-like structure and lands cocooned within gas-filled airbags. The outer shell provides energy absorption and thermal insulation within a casing that must spreads the impact loads and resists tearing. Many of the Beagle 2 science instruments are integrated with a robotic arm that transports them to deploy them in positions where they can study or obtain samples of the rocks and soil. Sub-surface samples are obtained using a Pluto (PLanetary Undersurface TOol) which has the ability to crawl across, and burrow below the planetary surface.

The constraints placed on Beagle 2 by mass restrictions of the Mars Express mission has meant that many innovations are necessary to ensure delivery of a suffieicnt science payload mass capable of the full range of measurements necessary to achieve the mission objectives. In particular a highly integrated approach to lander ssytems and science instruments has been essential. This approach and the necessary technology developments have important implications for future in-situ analyses of the Martian surface and sub-surface.

A MARS EXPLORATION DISCOVERY PROGRAM. C. J. Hansen[1] and D. A. Paige[2], [1]JPL, Mailstop 169-237, 4800 Oak Grove Dr., Pasadena CA 91109, USA (candice.j.hansen@jpl.nasa.gov), [2]Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90024, USA (dap@thesun.ess.ucla.edu).

The Concept: The Mars Exploration Program should consider following the Discovery Program model. In the Discovery Program a team of scientists led by a PI develop the science goals of their mission, decide what payload achieves the necessary measurements most effectively, and then choose a spacecraft with the capabilities needed to carry the payload to the desired target body. The primary constraints associated with the Discovery missions are time and money. The proposer must convince reviewers that their mission has scientific merit and is feasible. Every Announcement of Opportunity has resulted in a collection of creative ideas that fit within advertised constraints.

Following this model, a "Mars Discovery Program" would issue an Announcement of Opportunity for each launch opportunity with schedule constraints dictated by the launch window and fiscal constraints in accord with the program budget. All else would be left to the proposer to choose, based on the science the team wants to accomplish, consistent with the program theme of "Life, Climate and Resources". A proposer could propose a lander, an orbiter, a fleet of SCOUT vehicles or penetrators, an airplane, a balloon mission, a large rover, a small rover, etc. depending on what made the most sense for the science investigation and payload. As in the Discovery program, overall feasibility relative to cost, schedule and technology readiness would be evaluated and be part of the selection process.

What are the advantages of this concept? The scientific exploration of Mars will drive the program goals, rather than having the goals driven by a set choice of a particular vehicle (orbiter, lander, rover) in a given launch opportunity. Every opportunity the Program office will have the chance to change direction based on technological innovations and the science results of the previous missions. The science community is not locked into an architecture of, for example, ever bigger rovers and nothing else. The science community is free to propose the best payload and vehicle to accomplish their science goals. The proposers must convince a peer review panel that their science investigation is the next logical step in the exploration of Mars. Creativity and understanding of driving objectives are placed in the hands of the planetary science community. The only real constraints imposed are time and money.

Every opportunity NASA HQ would be selecting from a new batch of peer-reviewed proposals developed to return new important science data, unfettered by previous programmatic decisions on rovers vs. Landers vs. Orbiters vs. Scouts, etc.

As in the Discovery program, enthusiasm for new technology will be tempered by the low risk nature of inherited designs and hardware. The best proposals will contain a blend of both that is optimized for the opportunity and the science requirements. Technical and management review of the proposals should emulate the level carried out currently by the Discovery Program. This process gives NASA headquarters the opportunity to select a new approach without being tied to a rigid program plan. It is also robust to mission failure, as future missions are not so tightly tied to previous missions.

How do sample return and human exploration fit in? Sample return and human exploration should be fully acknowledged goals of the Mars Discovery Program.

Proposals that make progress toward sample return and human exploration should get "extra credit" in the proposal selection process. In order to make this happen, the entire list of prerequisites for both these goals should be generated. The lists will include everything from labs on earth to tests on Mars, for example of soil toxicity or *in situ* fuel production. Items on the list that should be either implemented or tested on earth or in earth orbit should be supported separately by the program, as described below. Experiments that must be carried out or technology that must be tested on Mars would be assigned a value, i.e. "bonus points" in the selection process. Proposals for Mars science missions would earn credit for each item they check off the to-do list.

Making progress toward sample return and human exploration thus become part of the selection process, again with the proposer empowered to select which piece fits best with their overall experiment plan. The PI is in fact motivated to include these items as it improves their prospects for selection. Again appealing to the Discovery Program as a model, we note that this has worked very effectively for advancing NASA's education and outreach efforts.

What about technology development? Unlike the Discovery Program, technology development is key in the Mars Program to advancing toward a greater assortment of vehicles capable of landing, flying, or operating in orbit at Mars, as well as having mobility on the surface. A specific percentage of the yearly Mars Program budget should be set aside for improvements in entry, descent and landing systems, sample handling systems, mobility, instrument development, etc. Many technology developments can and should be tested on earth or in earth- orbit before they are sent all the way to Mars. Facilities for eventual housing and analysis of Mars samples may need to come out of this separate line of funding also.

Managing the technology development effort would be an important role the Program Office would play. Proposals in any given opportunity could be used as a window into where development dollars would be most effectively invested for future missions.

The challenge of sending humans to Mars has a number of prerequisite goals, which should be addressed in a separate but coordinated manner. For example, long-term effects of living in space should obviously not be managed as a part of this program but will certainly proceed in parallel and must be taken into account in the decision as to when all the prerequisites have been met and we are ready to begin human exploration of Mars.

How would this concept be implemented? When? This concept will require a standing Program Office charged with providing the infrastructure for a diverse series of missions. With the 26 month timescale imposed, the process of writing Announcements of Opportunity and selecting missions must be a routine endeavor. The Program Office will need to keep close watch on the funding profile, and determine for any given launch opportunity the budget the proposers will have to work with to build, launch and operate their mission.

The Program Office will also be tracking progress toward the goals of sample return and human exploration. Note that the actual dates of sample return and human exploration are not fixed or even targets, but rather are determined by the rate of progress toward being ready to carry them out. The rate of progress toward these goals will reflect the priorities of the science community as well as the realities of the fiscal environment.

If this results in progress that is deemed too slow, or if significant new technology is ready to be tested at Mars and requires a substantial amount of resources, the Program Office can choose to replace a science mission with a technology demonstration. The next opportunity would then return to scientific exploration as its driving objective.

It will take time to put the program infrastructure in place and start the process. We would suggest that the first mission to be selected in this manner be for the '07 launch opportunity.

The exploration of Mars is an ongoing endeavor and will continue for decades. (We have been exploring the Earth for centuries.) There should never be a mission that represents a definitive end to the program of Mars Exploration. We need a program with enough inherent flexibility to continue indefinitely.

CHIRP TRANSFORM SPECTROMETER FOR THE EXPLORATION OF THE MARS ATMOSPHERE.

P. Hartogh , Max-Planck-Institut für Aeronomie, Max-Planck-Str. 2, 37191 Katlenburg-Lindau, Germany, e-mail: paul@chirp.mpad.gwdg.de

Microwave remote sensing has been proven to be a powerful tool for both basic research of the Earth atmosphere and environmental monitoring. Based on the experience derived from large missions like ATLAS and UARS new key technologies have been developed with the goal of minimizing costs, mass, power consumption and maximizing of functional performances. Potential future applications are terrestrial as well as extraterrestrial missions with small spacecraft resources of mass and power. In this presentation a key technology of microwave spectrometer backends will be described: the Chirp Transform Spectrometer (CTS). Past and present backend developments will be illustrated comparing the Microwave Atmospheric Sounder on ATLAS I-III (1991-93) with the Microwave Instrument of the Rosetta Orbiter to Comet Wirtanen (spectrometer Flight Model delivery July 2000) and the Microwave Instrument on Mars Express. New developments focussing on the Mars exploration of the future will be addressed.

Why send the Athena Raman spectrometer to Mars? Larry Haskin, Alian Wang, Bradley Jolliff, and Karla Kuebler, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130.

Mineralogy allows us to determine past Mars environments, including water activity and habitability. Whether the goal is to assess whether life might have evolved on Mars or to understand the broader geologic history of Mars, knowledge of past environments is key. The surest approach to seeking evidence for conditions under which life might have formed is to look for minerals formed in or altered by aqueous environments and to identify materials that might contain carbonaceous remnants of life [1]. This can be most comprehensively done in terrestrial laboratories, working with samples judiciously chosen on the basis of good field study. Selecting the best samples of Mars rock for study on Earth requires characterization of landing site geology and determination of the variety of materials at hand. This in turn requires definitive mineralogical information, which itself yields information on past environments. This field-based information is best obtained by Raman spectroscopy.

Raman spectroscopy provides definitive, detailed mineral characterization. "Definitive" characterization means accurate identification of major, minor, and trace minerals, determination of the proportion of each in a rock or soil, and determination of mineral chemical composition. Because we know the chemical and physical conditions under which individual minerals form, from this characterization we learn about past martian environmental conditions. The ability of Raman spectroscopy to provide definitive, detailed mineral characterization is indicated in Fig. 1 for the Martian meteorite EETA79001.

The record of alteration in surface rocks on Mars is expected to reach back in time from relatively recent alteration of rock surfaces, to past stream and lake environments, to hydrothermal settings of the upper martian crust, to the planet's early igneous chemical differentiation. By combining information about these past environments with the results of a search for organic carbon and inorganic reduced carbon, which Raman spectroscopy can also identify, we can speculate rationally on the possible development of life on Mars. Accurate determination of environmental conditions requires a Raman spectrometer of near laboratory capability [2]. The miniaturized Athena Raman spectrometer is of this caliber [3].

Raman spectroscopy can identify oxyanionic minerals (e.g., SO_4^{2-} , CO_3^{2-}, PO_4^{3-}, silicates) and oxide and sulfide minerals (e.g., hematite, pyrrhotite). As examples, spectra of silicate minerals from a Martian meteorite are included in Fig. 1. For other examples, see [3]. Also, Raman spectroscopy can determine cation mole fractions for Ca^{2+}, Mg^{2+}, and Fe^{2+} in minerals [4,5], key to establishing crystallization

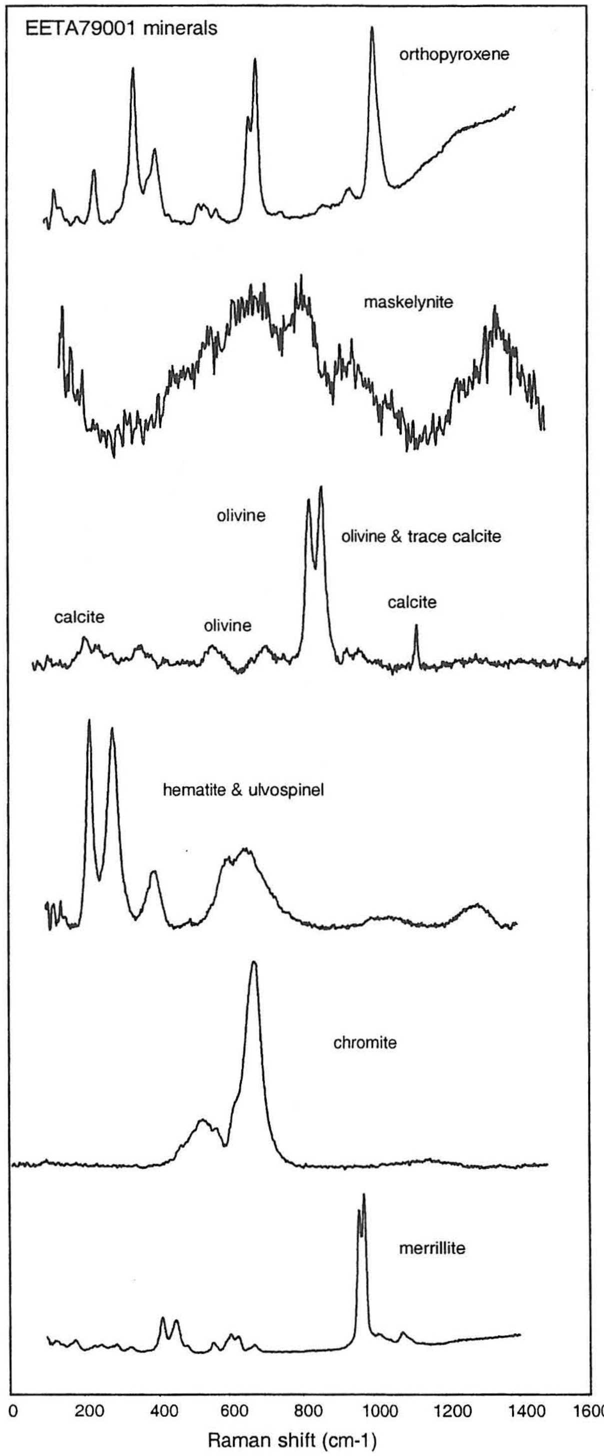


Fig. 1. Spectra of minerals in EETA79001 taken with a commercial Raman spectrometer. Ten seconds per spectrum.

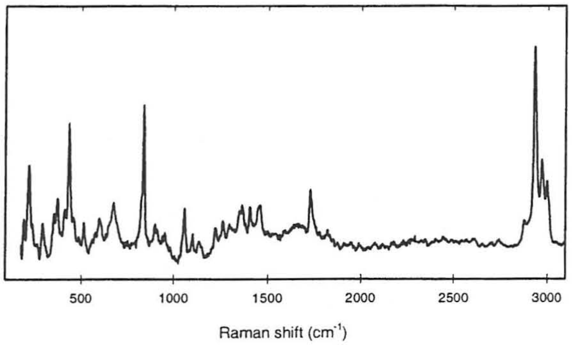


Fig. 2. Spectrum of the wax coating on a tiny crustose lichen encountered during a point-count scan on a basalt.

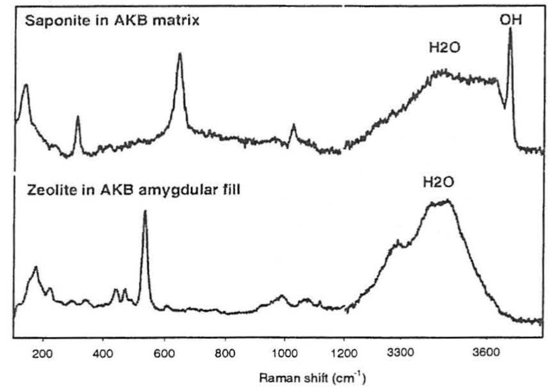


Fig. 3. Alteration minerals zeolite and saponite from a basalt. Note the water and OH peaks at high Raman shifts.

histories and environmental conditions.

Raman spectroscopy can observe organic materials (natural compounds, kerogen-like polymers) and reduced inorganic carbon. See, for example, the spectrum of the wax coating of a tiny (100 μm) crustose lichen on the surface of a weathered basalt [6] in Fig. 2, and the spectra of formerly organic carbon in an ancient chert [3,7]. It would take great luck to find remnant C of possible biological origin at a landing site.

Raman spectroscopy can observe water and OH if they are present in rocks and soils. Examples are the spectra of a saponite clay and a zeolite (Fig. 3), both hydrothermal alteration products in a basalt. These minerals indicate that the basalt was altered in an oxidizing, hydrothermal environment between 250 and 350 °C [6]. Raman spectra thus provide information on conditions under which life might have begun or evolved even if we fail to find carbon-bearing materials that were generated in those environments.

Special preparation of samples is usually not needed. A fortunate attribute of Raman spectroscopy is that the principal minerals in a rock can commonly be identified in rocks as found, except where coatings are thick [8]. On Mars, dust coatings are intermittent, and wind-scoured surfaces are present [9], so dust should not be a crippling problem. Varnish coatings, if present, represent more of an opportunity than an obstacle; their Raman spectra will enable us to determine environmental conditions of surface weathering.

Close-up, microbeam mineralogy is required to search for hydrothermal and surface-water alteration minerals. Mars mineralogy as known from orbit [10] indicates that most rocks are volcanic. No carbonate, quartz, olivine, or hydrous minerals have been reported. Patches of hematite were found, but other products of alteration may be scarce, as they are in SNC meteorites.

Identification of a single mineral is rarely sufficient to determine the environment of formation or alteration of a rock. Knowledge of the assemblage of minerals is required, including minor and trace minerals. Also, grain sizes and spatial relationships among minerals may be required. Determining the mineral assemblage and the spatial relationships requires a simple image, and this can be obtained by a linear point-counting traverse [11]. During a point-count scan of Martian meteorite EETA79001, the 281 cm^{-1} and 1187 cm^{-1} peaks of trace carbonate stood out above a background spectrum of pyroxene (Fig. 1).

The mineralogy determined by Raman spectroscopy complements that from other Athena instruments. The Raman spectrometer is a microbeam instrument capable of detecting minor and trace minerals, water, and organic and reduced inorganic carbon. By point-counting, it provides nearly comprehensive mineral identification, mineral proportions, and rock texture. The Mössbauer spectrometer, which senses cm-scale patches of rock or soil, determines the presence of Fe-bearing minerals and how the iron is distributed among them. The Pancam and mini-TES instruments observe cm-scale patches from a distance and obtain an averaged signal from the suite of minerals in the targeted area. They can locate targets for close-up study by the Raman spectrometer, the Microscopic Imager, and for coring.

References: [1] NASA SP530, Exobiology Strategy for Mars Exploration [2] Wang, A. et al., Appl. Spectr. 52, 477, 1998; [3] Wang, A. et al., abstr., this vol.; [4] Wang, A. et al., Lunar Planet. Sci., abstr. 1875, 2000; [5] Wang, A. et al., JGR 104, 8,509, 1999; [6] Wang, A. et al., JGR 104, 27,067, 1999; [7] Wdowiak, T. et al., abstr., Conf. Early Mars, Houston, 1997; [8] Israel, E. et al., JGR 102, 28,705, 1997; [9] Greeley, R. et al., JGR 104, 8,573, 1999; [10] Christensen, P. et al., JGR 105, 9,609, 2000; [11] Haskin, L. et al., JGR 102, 19,293, 1997.

MarsLab: A HEDS Lander Concept. M.H. Hecht[1], C. McKay[2], G. Briggs[2], and J. Connolly[3] , [1]Jet Propulsion Laboratory, [2]NASA Ames Research Center, [3]Johnson Space Center.

Introduction: Recognizing that the human exploration of Mars will be a science-focused enterprise, the Human Exploration and Development of Space (HEDS) program set out three years ago to develop a mix of science and technology Lander payloads as a first step toward a human mission.

With three experiments ready for flight and four more in development, the HEDS Mars program has the capability to stage missions with considerable impact. This presentation describes one such mission design, by no means unique. Ambitious in scope, it encompasses elements of all seven HEDS payloads in a configuration with a uniquely HEDS character. Pragmatically, a subset of these elements could be selected for existing small Lander platforms.

Bristling with scientific experiments, technology demonstrations, and outreach elements, MarsLab represents a prototype of a manned science station or scientific outpost. A cartoon overview of MarsLab defines its major elements, explained more fully in the sections that follow. The concept is endorsed by PI's of the various HEDS payloads, details of which are presented elsewhere at this workshop.

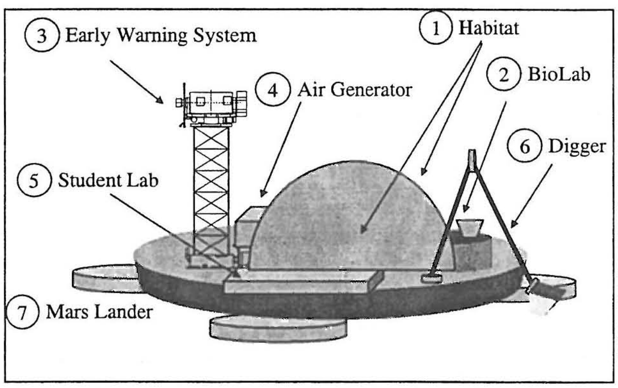


Figure 1: Elements of MarsLab based on the 7 HEDS payloads. Habitat includes MARIE and/or MANES science. BioLab, focused on astrobiology, houses MECA and MOD. MATADOR constitutes the Early Warning System. The Air Generator draws from MIP and PROMISE, while Student Lab draws from MECA and MPL. The Digger is possibly the robot arm and camera from MPL. The Mars Surveyor '01/'03 platform is preferred for the Lander itself.

1. Habitat: Astronauts will require a home base that provides for their physical well-being and houses their scientific laboratories. Prototyping such an environment, Habitat would consist of an inflated dome with a controlled atmosphere, thermal management, and an environmental monitoring suite. The atmosphere would be maintained by the Air Generator discussed below, and monitored (at a minimum) with a microfabricated ion mobility spectrometer developed by Draper Laboratories for ISS [1]. Habitat would provide a controlled, pressurized environment for some of the BioLab sensors and other environmentally vulnerable components.

Transparent in the visible and opaque in the infrared, the dome would demonstrate greenhouse technology to reduce the power burden on a martian outpost. A selectively absorbing surface, minimizing emissivity to the cold martian night sky, may be enhanced by a mechanical or electrochromic reflective night cover. While these greenhouse principles are well understood, an *in situ* demonstration evaluates performance degradation due to wind, surface dust, atmospheric absorption, sky temperature, or mechanical hazards.

A solar concentrator at the top of the dome focuses sunlight in a dual gap GaAs solar cell, highly efficient in concentrated sunlight, with waste heat captured by a phase change material. This heat capture keeps daytime temperatures low, reducing radiation loss, and raising night-time temperatures.

In addition to the atmospheric diagnostics, ionizing radiation is monitored by the **MARIE** [2] and **MANES** payloads. Other sensors monitor temperature, pressure, and general state of health.

2. BioLab: While robots are effective for studying geology or meteorology, it will likely be *human* exploration that will put to rest questions of martian astrobiology. When the first astronauts spend 500 days on Mars, the focus of their activitities will be a bio-lab. The MarsLab version addresses questions of organics and oxidants left unanswered by Viking, while characterizing the site for its ability to preserve markers of biology or evidence of a biocompatible habitat.

From the **MECA** [3] experiment, BioLab draws on the microscopy and wet chemistry stations. MECA combines optical and atomic force microscopy (AFM) to image particles from nanometers to millimeters in size under a controlled environment. Analytical tools include 3-color illumination, UV fluorescence, and an abrasion tool. Chemical and mineralogical analysis of individual particles could be achieved by adding Raman spectroscopy or laser-induced breakddown spectroscopy to the AFM (W. T. Pike, private communication; D. Kossakovski, private communication).

MECA's chemical laboratory accepts samples from the soil hopper, mixes them with a leaching solution, and performs electrochemical analysis. Ion-specific electrodes (ISEs), dissolved gas sensors, cyclic voltammetry, and anodic stripping voltammetry will probe pH, redox potential, and conductivity, and ions including Na^+, K^+, Ca^{++}, Mg++, NH_4^+, Cl, SO_4^-, HCO_3^-, Cu^{++}, Pb^{++}, Cd^{++}, Hg^{++}, and ClO_4^-.

MOD [4] assesses the presence or absence of key organic compounds in martian rock and soil. It uses sublimation to extract samples from a crushed rock mineral matrix and analyze them with a fluorescence detector and tunable diode lasers. In addition to specificity for amino acides, amines, and PAH's, MOD will quantify adsorbed and chemically bound water and CO_2, including a determination of isotopic abundances.

MAOS, a MATADOR element, characterizes oxidants in the atmosphere and soil. A compact, low power instrument, MAOS consists of a chemiresistor array and selective air, dust, and UV filters.

3. Early Warning System: Mars presents a desolate, windswept landscape, periodically disturbed by dust-laden vortices and sky-obscuring storms. As in terrestrial deserts, dust permeation and obscuration (and coincident electrical effects) can threaten either manned or robotic missions.

Born from a combination of the MITCH and ECHOS proposals to the '03 Lander, **MATADOR** combines remote and in situ studies of martian weather systems, particularly dust devils and storms. Scanning LIDAR (contributed by CSA), boresighted with a camera, will spot dust devils in a manner akin to airport radar. Electric field and radio noise sensors provide additional storm warning, including estimates of direction and magnitude. Conventional meteorology instruments (pressure, temperature, wind) monitor these systems as they pass, while dust and triboelectric sensors monitor the synergistic effect of the wind/dust/electrostatic system.

An extension of the MOD tunable diode laser analyzer adds atmospheric analysis, including isotope ratio determination, to recover lost MPL science.

4. Air Generator: The pragmatic path to Mars has astronauts "living off the land," particularly with respect to fuel and breathable air. Using sorption and heating to compress carbon dioxide from the martian atmosphere, **MIP** [5] generates oxygen with zirconia catalysts. **PROMISE**, representing the next generation chemical laboratory, adds breathable buffer gases. Together with their diagnostic sensors, they will test a closed-loop system to maintain breathable air in the dome with *in situ* resources.

5. Student Lab: Today's students will be among the first martian astronauts. MarsLab will make the martian surface accessible to a few of them. The Planetary Society's Mars Microphone, lost on MPL, will anchor a "Sights and Sounds of Mars" module. A second module will solicit student participation in a *powered* version of the MECA patch plate experiment. This concept expands on the "Student Nanoexperiment Challenge" that competitively involved students in MSP'01. Student-designed flight modules will be fabricated by a designated contractor in a standardized format. Images of the modules, before and after soil deposition, will be returned with and without power.

6. Digger: An instrumented digging device will collect soil and/or rock fines for deposition in a hopper for BioLab experiments. Preferred is the robot arm and camera designed for the MPL and MSP'01 platforms. This arm would be instrumented with a camera, the MECA electrometer, and possibly MAOS. The electrometer will measure triboelectric charging from soil as well as atmospheric charge transport and local electric fields.

7. Lander Platform: For HEDS, the spacecraft itself is a key part of the experiment. The HEDS reference mission demands demonstration of aerobraking, precision landing, and other spacecraft functions. For this reason, the original MSP'01, MSP'03 series is preferable to a Pathfinder-style lander - but the payload is not hostage to either design.

Summary: MarsLab is an integrated package that addresses in situ analysis and human exploration with a healthy balance of science content and development risk. Built around peer-reviewed HEDS payloads, MarsLab is readily achievable for the 2005 opportunity. Moreover, a significant subset can be readied for 2003. Publically engaging, MarsLab will return valuable science and validate engineering concepts for Mars habitation.

References: [1] R.A. Miller, G.A. Eiceman, E.G. Nazarov, T.A. King, in Solid State Sensor and Actuator Workshop 2000, Transducers Research Foundation, Inc. [2] G.D. Badhwar in *Mars 2001: Integrated Science in Preparation for Sample Return and Human Exploration*, LPI Contribution No. 991, Oct. 2-4, 1999, p. 17 [3] T.P. Meloy, J. Marshall, M. Hecht, *ibid,* p. 74 [4] G. Kminek et al., *ibid*, p. 60, [4] D.I. Kaplan, *ibid*, p. 54.

The Mars Environmental Compatibility Assessment (MECA). M. H. Hecht[1], T. P. Meloy[2], and J. R. Marshall[3], [1]Jet Propulsion Laboratory (M/S 302-231, 4800 Oak Grove Dr., Pasadena, CA 91109), [2]W. Virginia Univ. (P.O. Box 6070, Morgantown, WV 26506), [3]SETI Institute (Moffet Field, CA 94035-1000).

Introduction: Originally selected for the HEDS dust & soil payload for the 2001 Mars Surveyor Lander, The Mars Environmental Compatibility Assessment (MECA) has now been completed, tested, and is ready for flight. This paper will review the four MECA instruments.

Microscopy: Figure 1 illustrates the microscope station, consisting of a two degree-of-freedom sample stage, an optical microscope in the horizontal orientation, and a small atomic force microscope. Characteristic data from the optical microscope is shown in figure 2, from the AFM in figure 3.

Several types of substrates substrates separate the soil into distributions that preferentially adhere to metals, insulators, magnets, sticky polymers, or textured materials. At least one sample from each set falls in a small "bucket" to be examined in bulk. After loading, the stage retracts into the darkened enclosure, then approaches the microscopes. An abrasion tool can optionally rub the samples against quartz and glass substrates to help determine their hardness.

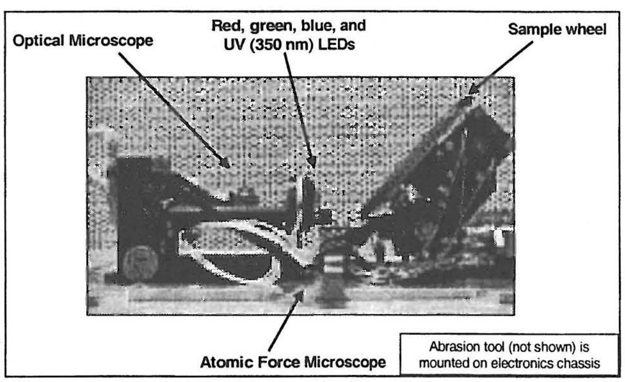


Figure 1: MECA Sample wheel on left, optical microscope on right, and AFM in center

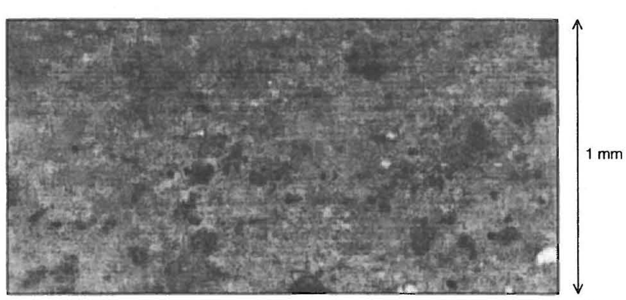


Figure 2: This optical microscope image of a particle field (256 x 512) is a composite of 3 pictures taken under red, green, and blue illumination

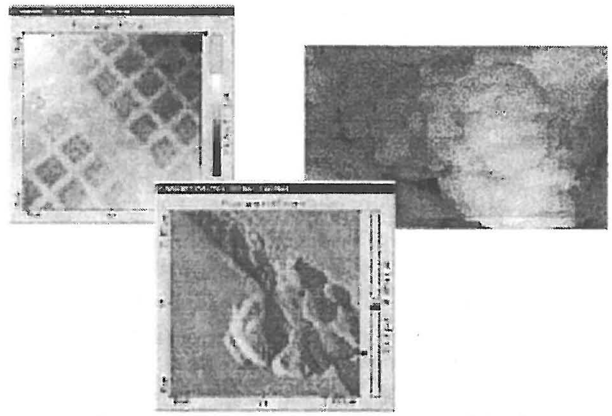


Figure 3: Low (53 µm scan range) and high (2 µm range) resolution AFM image of a dusty calibration grid. Colors indicate height. An ~10 micron aggregate of basalt particles from an ultrasonic drill is at far right

Illuminated by red, green, blue, and ultraviolet LEDs, the fixed-focus 6x optical microscope represents a compromise between resolution and depth-of-field. As the CCD is blind in the ultraviolet, UV-stimulated fluorescence may be observed.

Chemistry laboratory: Four independent, single-use modules receive soil samples from the robot arm and actively mix them with a leaching solution in a pressure vessel for electrochemical analysis. Ion-specific electrodes (ISEs), dissolved gas sensors, cyclic voltammetry, and anodic stripping voltammetry will probe pH, redox potential, and conductivity, and ions including Na^+, K^+, Ca^{++}, Mg++, NH_4^+, Cl, SO_4^-, HCO_3^-, Cu^{++}, Pb^{++}, Cd^{++}, Hg^{++}, and ClO_4^-.

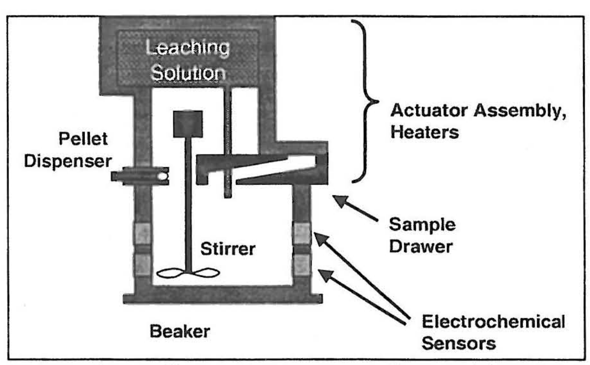


Figure 4: An illustrative version of one of four MECA chemistry cells.

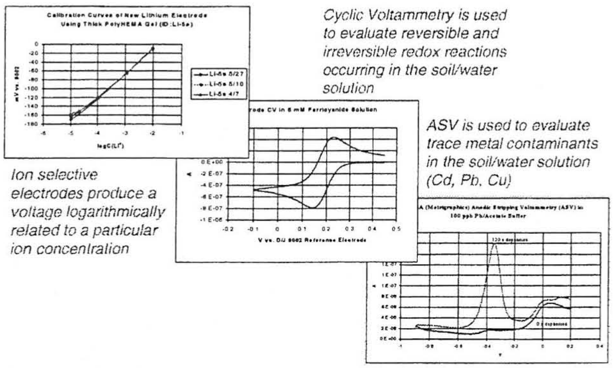


Figure 5: Characteristic plots of ion concentration, cyclic voltammetry, anodic stripping voltammetry.

Electrometer: From the MECA electrometer (figures 5 and 6), we learn about triboelectrification and its role in particle transport; atmospheric ionization; and local electric fields which can act as an energy source for ion absorption, chemical reaction, and biological processes.

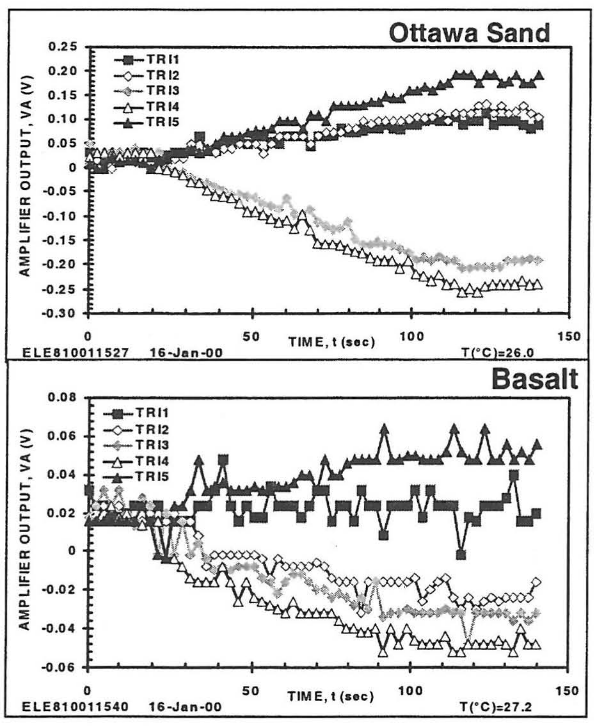


Figure 5: Triboelectric response of five sensors to two types of soil. The polarity of each response is a signature of the soil characteristics. Charging was measured as sand was "rocked" across the 5 sensors. The charging may be positive or negative, fast or slow, depending on both the sample and the sensor material.

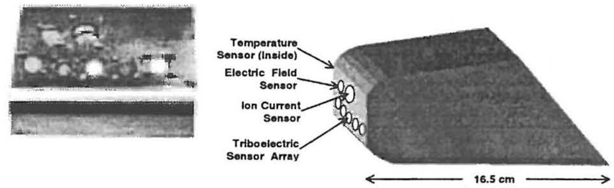


Figure 6: Just as our bodies charge up from walking across a rug in cold, dry places, objects rubbed across the ground will tend to charge in the cold, dry atmosphere of Mars. Mounted on the heel of the robot arm scoop, the electrometer measures such electrostatic hazards, and also tells us about the nature of the soil, its composition, surface chemistry, and how it is carried from place to place.

Patch Plates: Nearly 100 samples are imaged on the deployable Patch Plate, including student nano-experiments. By photographing the plates after exposure to air, soil, and "jostling" with the robot arm, we will observe how dust adhesion depends on conductivity, electric and magnetic fields, texture, and other properties of materials.

The patch plates also carry "Nano-experiments" include a magnetic compass and phosphors sensitive to ultraviolet light. There are also *student* nano-experiments, contributed by The Planetary Society.

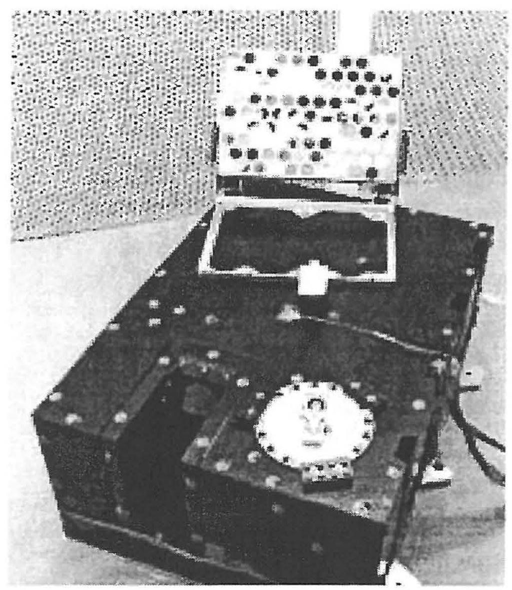


Figure 6: Rear left is the deployed Patch Plate. Front right is the Planetary Society commemorative CD. Front left is sample introduction for the microscope, and to the right are 4 sample entry slots for the chemical laboratories

AN ULTRAVIOLET-VISIBLE IMAGING SPECTROMETER FOR A MARS '05 ORBITER. A. R. Hendrix,[1] W. R. Pryor[1], W. E. McClintock[1], L. W. Esposito[1], A. I. F. Stewart[1], [1]Laboratory for Atmospheric and Space Physics, Campus Box 590, University of Colorado, Boulder, CO 80309, hendrix@lasp.colorado.edu.

Introduction: We propose an imaging spectrometer covering ultraviolet through visible wavelengths for an upcoming Mars orbiter mission. This instrument will fulfill the goals of monitoring Mars' atmosphere and further understanding surface compositional variations. Such an instrument will enhance our understanding of the Mars environment as is pertinent for impending human missions. Our goals are 1) to perform measurements of the surface, both in the polar regions and at lower latitudes, in particular to look for and map H_2O_2, and 2) to perform measurements of the atmosphere to monitor temporal variations in ozone and other species.

Surface Measurements: Ultraviolet spectroscopy can be used to characterize the oxidizing properties of the martian surface. We are currently undergoing an analysis of Mariner 9 UVS spectra of Mars' polar regions to look for the UV signature of hydrogen peroxide (H_2O_2). Based on theory, we believe H_2O_2 is present on the polar caps and in the soil of Mars. Viking results indicate that an oxidant is likely present on the surface that destroys organic material [1],[2]. Hydrogen peroxide is a primary candidate for the oxidant, as it is easily produced by photodissociation of water vapor [3]; thus far, however, H_2O_2 has not been identified either in the soil or on the polar caps.

We now have a proven method of detecting H_2O_2 on icy surfaces and plan to apply this method to Mariner 9 UVS data of Mars' polar caps. Galileo UVS data of Jupiter's icy moon Ganymede display absorption features due to both ozone and hydrogen peroxide (Fig. 1) [4],[5]; we will look for similar features in the Mariner 9 UVS polar cap data.

A cursory look at two Mariner 9 UVS spectra of the south polar cap show that it varies spectrally during the year. As shown in Fig. 2, the south polar cap displays an ozone signature in the late summer, while it displays a completely different spectrum during the mid-summer. By comparisons with Ganymede UV spectra, we believe that this is the signature of H_2O_2 on Mars' polar cap. The presence of peroxide on the polar caps would suggest that it is likely also present in the martian soil. An ultraviolet imaging spectrometer with a spatial resolution of at least 5 km can be used to look for H_2O_2 in regions on the martian surface; in particular, we plan to look in the regions where TES has detected hematite.

Ozone is known to be present in Mars' polar regions [6],[7],[8] and is likely produced by photochemistry of atmospheric CO_2. The polar cap ozone and hydrogen peroxide are likely related, as hydrogen peroxide may contribute to the destruction of the ozone [9]. The analysis of hydrogen peroxide on Mars is therefore important not only to understand the lack of organic material but to understand the complete CO_2-H_2O-O_3 cycle. The Mariner 9 UVS data may provide a first clue to the presence of H_2O_2 on Mars; a higher spatial resolution UV imager on an '05 orbiter will afford a more complete picture.

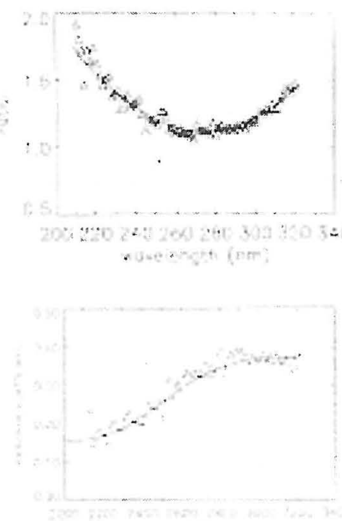


Figure 1. Galileo UVS data of Ganymede. Top panel shows ozone-like absorption feature in a ratio of a south polar spectrum to an equatorial spectrum. Bottom panel shows a spectrum of a leading hemisphere region which shows the hydrogen peroxide characteristic. The top panel shows a ratio of measured spectra, while the bottom panel shows the measured "radiance coefficient," which is the measured reflectance divided by the cosine of the solar incidence angle.

Atmospheric Measurements: The focus of this aspect of our investigation is to determine atmospheric components and variations on a variety of temporal scales, to more fully grasp the phenomena of the martian atmosphere prior to sending humans to Mars. This understanding is vital both for the orbital insertion as well as for ground-based operations of a manned mission.

Ozone was discovered on Mars using ultraviolet data from Mariner 7 [7]. A broad absorption feature centered near 2600 Å was detected by ratioing a south polar cap (65° S) spectrum to an equatorial (1° S) spectrum; this band was found to be similar to the

Hartley ozone absorption band. Further measurements using the UVS on Mariner 9 [6] displayed ozone both associated with the polar hood and at the polar caps; at low latitudes, no ozone was ever detected above the detectable level. A modern UV imaging spectrometer will monitor atmospheric O_3 levels and study variations with H_2O, H_2O_2, season and diurnal cycles.

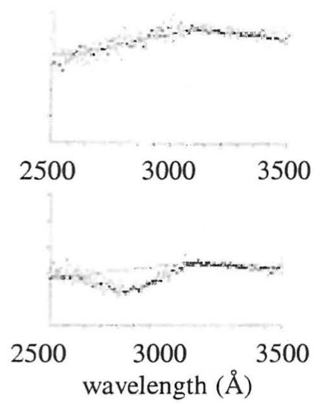


Figure 2. Mariner 9 data of the south polar cap (Barth, unpublished data). Shown are measured reflectances; the y-scale is from 0.0 to 0.05 on both plots. The bottom panel displays the ozone absorption band while that feature is absent from the top spectrum. Both spectra were taken of the southern polar cap (85° S); the top panel was taken in mid-summer (orbit 124) and the bottom spectrum was taken in late summer (orbit 184).

UV airglow measurements of Mars provide information on the upper atmospheric abundance and distribution of H, He, C, O, CO, and CO_2. H is derived from photolysis of water vapor; UV measurements at 1216 Å are important for determining atmospheric escape rates. Other products of water photolysis include OH, H_2, HO_2, and H_2O_2. He 584 Å was recently measured for the first time by EUVE [11]. O, C and CO are derived from photolysis of CO_2. O 1304 Å emissions are a useful tracer of dynamical processes in the upper atmosphere. Efficient modern UV spectrometers with array detectors and several Å spectral resolution may also permit studies of other species such as N_2, N, NO, and Ar. Past measurements by the Mariner UV spectrometers have provided a basic inventory of the atmosphere, but future studies are needed to study diurnal, seasonal and solar cycle changes in the upper atmosphere.

Limb measurements in the UV are a good way to study the ionospheric airglow layer and its variations. UV limb measurements found intense Cameron band emissions of CO from 1900-2700 A, which are primarily produced by dissociative excitation of CO_2 by ionospheric photoelectrons and by photons. CO_2^+ emissions at 2890 A and from 3000-4000 A are produced by the photoionization of CO_2. Limb measurements on Mariner 9 also proved useful for studying thin Martian hazes and clouds, because of the slant path enhancement at the limb [12].

Dust measurements can also be made using ultraviolet techniques. On Mariner 9, the Rayleigh scattering column found with the UVS was used to infer the Martian topography, with an unknown correction for dust opacity. Now that the topography is well known from the Mars Global Surveyor laser altimetry, the UV data can be used to deduce the dust opacity and its variations.

UV solar and/or stellar occultations at Mars may also prove useful in studying changes in atmospheric scale height. Carbon dioxide absorbs strongly at wavelengths below about 1900 Å, providing a good opacity source. Changes in the CO_2 column density at a given altitude may be related to dynamical processes, diurnal heating and cooling, seasonal effects, or dust storm activity. Knowledge of the upper atmosphere, its density, and its variation is critical for planning aerobraking and aerocapture missions at Mars.

Instrument: To achieve the goals of determining H_2O_2 and O_3 abundances and seasonal variations in the polar regions, and further studying the atmospheric ozone and airglow, we propose the inclusion of an ultraviolet-visible imaging spectrometer on board an orbiter. This instrument will be identical to the Cassini UVIS (built at LASP), but will also include an NUV channel plus a visible channel, and will include a scanning mirror for increased spatial coverage.

References: [1] Hunten D. M. (1979) *J. Mol. Evol,. 14*, 71-78. [2] Bullock M. A. et al. (1994) *Icarus, 107*, 142-154. [3] Parkinson T. D. and Hunten D. M. (1972) *J. Atmos. Sci., 29*, 1380. [4] Hendrix A. R. et al. (1999) *LPS XXX*, 2043. [5] Hendrix A. R. et al. (1999) *JGR,. 104*, 14169-14178. [6] Barth C. A. et al. (1973) *Science*, 179, 795-796. [7] Barth C. A. and Hord C. W. (1971) *Science, 173*, 197-201. [8] Barth C. A. and Dick M. L. (1974) *Icarus, 22*, 205-211. [9] Hunten D. M. (1974) *Rev. Geophys. and Space Phys., 12*, 529-535. [10] Lane A. L. et al. (1973) *Icarus, 18*, 402-408. [11] Krasnopolsky, V. et al. (1994) *Icarus, 109*, 337-351. [12] Barth, C. A. (1992) Mars, 1054-1089.

Regolith Evolved Gas Analyzer (REGA): An Instrument to Characterize the Martian Soil Mineralogy and Atmosphere Composition

John H. Hoffman, Physics Department, University of Texas at Dallas, Richardson, TX 75083 jhoffman@utdallas.edu
David S. McKay, and Douglas Ming, NASA Johnson Space Center, Houston, TX 77058
mckay@snmail.jsc.nasa.gov, ming@snmail.jsc.nasa.gov
Carlton C. Allen, Lockheed Martin Space Operations, Houston, TX 77058, allen@snmail.jsc.nasa.gov
Jud Hedgecock, and Terry Nienaber, Oceaneering Space Systems, Houston, TX 77058
jhedgeco@oss.oceaneering.com, tnienabe@oss.oceaneering.com

This abstract describes an instrument and experiment to be proposed for a future Mars surface mission to conduct basic research on environmental characterization. The Regolith Evolved Gas Analyzer (REGA) experiment is designed to provide information on Mars surface material properties in preparation for human missions of exploration. The goals of the investigation are:

- Define and determine surface mineralogy of soil and dust and their effects on humans and machines.
- Conduct *in-situ* investigations aimed at identifying possible evidence of past or present life on Mars

These experiments are designed to answer important fundamental questions regarding the surface of Mars and its potential risks and hazards for its future exploration by humans such as:

1. Does the soil contain water, oxygen, and hydrogen needed for the survival of humans on the surface and their safe return to earth, and can these be extracted in sufficient quantities to support a human mission?
2. Is there evidence for life, past or present, in the surface materials?
3. Are there hazardous or toxic materials in the soils that could adversely affect humans and equipment or machines?

The REGA instrument consists of four primary components. These include a flight-proven mass spectrometer, a high temperature furnace, a microcontroller, and a soil handling system. Martian soil samples are deposited in the soil handling hopper where they are sieved and metered into a crucible for transport into a high temperature furnace. The furnace heating profile is controlled by the microprocessor to preprogrammed heating cycles. The furnace is capable of reaching a temperature of 900°C. As the sample is heated, evolved gases are transferred into the mass spectrometer for gaseous and isotopic analysis. Identification of evolved species and liberated chemicals, e.g. oxygen, sulfur, chlorine, and fluorine, is derived from the mass spectra. Besides the mass spectrometer, which has had previous flight experience, the soil handling system, furnace, and computer/microprocessor have been developed to a prototype stage.

REGA is uniquely qualified to provide specific mineralogical and chemical data that are important to understanding the geological and climatological history of Mars. This knowledge will help us identify previous conditions that may have supported life, and consequently the most likely places where evidence of life may be found. Of particular interest is the identification of areas containing carbonates and evaporites. These types of minerals could indicate the prior presence of water--a prerequisite for life. It is also expected, based upon Earth's microbial fossil record, that sedimentary precipitates such as carbonate, silica, and phosphate are the most likely samples in which evidence of life may be preserved.

The data to be provided by REGA on the mineralogical composition and chemical reactivity of the martian soil is also critical in assessing the possible environmental hazards to be encountered by future human explorers and their equipment. The hazards investigation is designed to identify and quantify volatiles as they are evolved during the heating of soil and dust that may be harmful to humans and equipment and machinery. Specifically, substances to be investigated include (1) the identification and quantification of O_2 evolved from the regolith to place constraints on distribution and chemical composition of the putative Mars oxidant, and (2) the identification and quantification of evolved gas (e.g., SO_2) from volatile-bearing minerals and phases (e.g., sulfates) as a function of temperature. A thorough understanding of the environment to be explored prior to a human Mars mission is essential to providing for the safety of the crew and operability of the engineering systems required to support their efforts.

The isotopic abundances of various volatile species in the martian soil and atmosphere, e.g. C, H, N, and the noble gases are derived from the mass spectra. Such data can add important constraints to interpretation of the degree of chemical and physical equilibrium (or lack thereof) between volatiles in the soil and in the atmosphere and to assessment of the source of water in surface samples. These constraints will add to our understanding of the climate and water history of Mars and the evolution of the atmosphere over time, and will help enable the search for major water or ice deposits.

REGA is also capable of chemical and isotopic composition monitoring of the martian atmosphere. When the mass spectrometer is not being used to measure evolved gases from the soil, it can be opened to the atmosphere (with an in-line dust filter) to conduct long-term monitoring of atmospheric constituents.

Soil and atmosphere data gathered by REGA will complement existing martian data and lead to new insights and discoveries about Mars. These new findings include:

- Identification of the molecular masses of all of the gases liberated from heated martian soil samples
- Identification of the martian soil mineralogy
- Identification of martian soil reactivity
- Existence of water in the martian soil
- Identification of potential toxic elements in the martian soil
- Identification and composition of gases in the martian atmosphere and how the composition varies on a daily basis.

A NEW GENERATION OF TELECOMMUNICATIONS FOR MARS: THE RECONFIGURABLE SOFTWARE RADIO, W. Horne[1] and J. Adams[2], [1]ITT Industries Advanced Engineering & Sciences Division, 1761 Business Center Dr., Reston, VA 20190, e-mail: william.horne@itt.com, [2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, e-mail: jta@jpl.nasa.gov

Introduction: Telecommunications is a critical component for any mission at Mars as it is an enabling function that provides connectivity back to Earth and provides a means for conducting science. New developments in telecommunications, specifically in software-configurable radios, expand the possible approaches for science missions at Mars. These radios provide a flexible and re-configurable platform that can evolve with the mission and that provide an integrated approach to communications and science data processing.

Deep space telecommunication faces challenges not normally faced by terrestrial and near-earth communications. Radiation, thermal, highly constrained mass, volume, packaging and reliability all are significant issues. Additionally, once the spacecraft leaves earth, there is no way to go out and upgrade or replace radio components. The reconfigurable software radio is an effort to provide not only a product that is immediately usable in the harsh space environment but also to develop a radio that will stay current as the years pass and technologies evolve.

Software Radios & Science Approaches: The only product generated by current and near-future robotic explorations of Mars is data. This data, once collected by science instruments on the remote spacecraft, must be transferred to Earth in order to have value. While communications is often viewed as "infrastructure," it plays a key role in meeting science objectives especially for *in situ* analysis and global reconnaissance. Figure 1 illustrates some of the uses of telecommunications in Mars exploration. Software configurable radios provide capabilities to support science and related activities as well as enable mission and science approaches, including:

Data Networking & Sensor Webs. The exploration environment at Mars will continue to evolve from a single spacecraft visit every few years to an armada of landed and orbiting spacecraft, all with the need to communicate their data back to Earth. Orbiting telecommunications assets will provide this long-haul function. Multiple users, various levels of data criticality, and huge data volumes will cause congestion if networking standards are not applied early and firmly. The reconfigurable software radio performs protocols and routing to enable internetworking and on-board routing (e.g., TCP/IP, distributed processing on-board where instruments perform their own processing). This internetworking capability enables mission approaches that exploit interconnected but distributed instruments, often called sensor webs.

Equipment Flexibility. Traditionally, telecommunications equipment destined for deep-space have been hardware-specific devices with modifications to its functionality limited to changes in data rate or coding. This is true for current Mars missions. The flexibility of software-configurable radios allow for updating processing, protocols, and other activities (useful for cross-support of science missions). The reconfigurability enables mission approaches that evolve over time.

Auxiliary Science. Software-configurable radios can support cross-link capabilities for occultation studies including the capability to perform beamform-

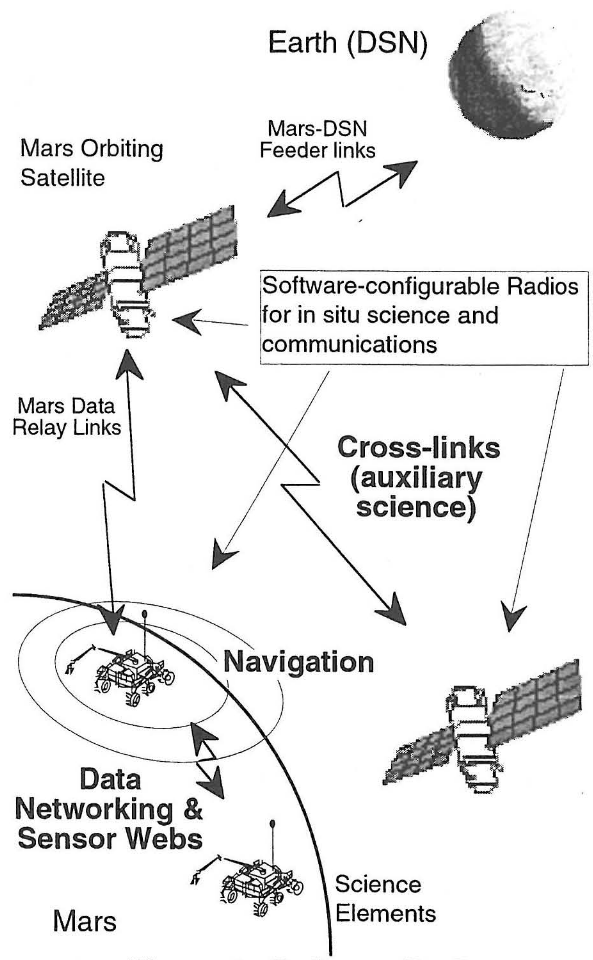


Figure 1. Software Radio Applications for Science

A New Generation Of Telecommunications For Mars: The Reconfigurable Software Radio
W. Horne and J. Adams

ing with a phased array antenna that can be used to assist in direction finding or tracking a spacecraft for closing cross-links. The digital nature of software radios enable a greater array of science measurements to be recorded from the received signals.

Navigation Utility. The users in the Martian environment not only need to move data but to know where they are so that the data has context. The software reconfigurable radio supports navigation and geolocation through better processing of Doppler, range, timing, and angle measurements.

Software Radio Overview: A software radio performs functions that are traditionally carried out solely in hardware, such as the generation of the transmitted radio signal and the detection and demodulation of the received radio signal, by using software residing in high-speed digital signal processors. Since these functions are carried out in software, the radio can be programmed to transmit and receive over a wide range of frequencies and to emulate virtually any desired transmission format. The operating parameters can be altered even after it is deployed by a simple software change. For example, a software radio could have the ability to transmit and receive using an existing protocol (e.g., CCSDS Return Telemetry) when launched, but it can then be updated at later date to handle a new protocol (e.g., CCSDS Proximity-1). The physical layer (e.g., PSK, FSK) processing can also be altered to support the needs of an evolving mission.

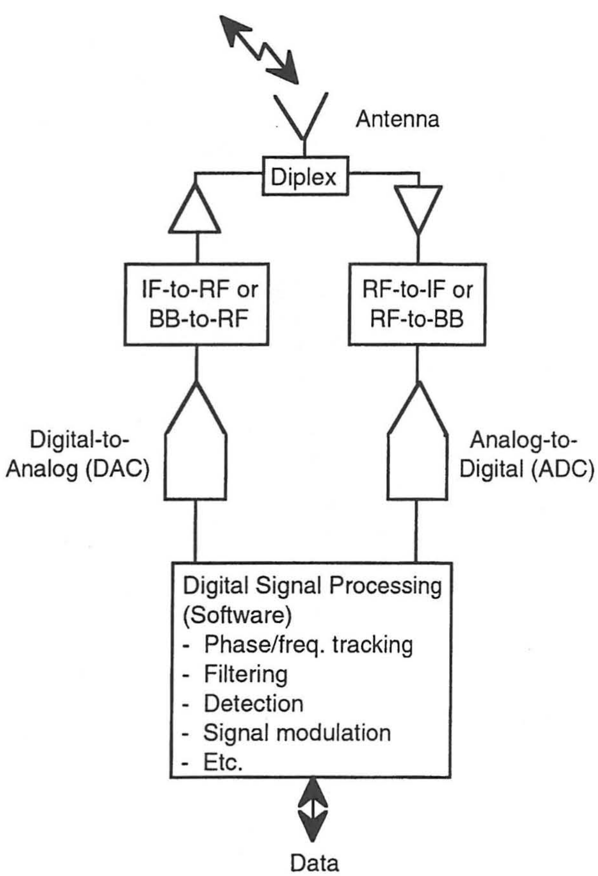


Figure 2. Fundamental Software Radio Architecture

The key component of a software radio is an architecture that uses high speed digital signal processing to perform signal transmission and reception. The radio design also needs to achieve favorable size, weight, and power consumption characteristics necessary for the space environment. Figure 2 illustrates the basic architecture that is used in a software radio. The architecture features digital signal processing that can be implemented using different devices including Field-Programmable Gate Arrays (FPGAs), microprocessors, and digital signal processing chips.

Development Path: Software radios are becoming more and more widely used in industry and commerce, but additional work needs to be conducted to prepare these radios for the space environment. As mission approaches are identified for exploring Mars, the requirements for communications should be communicated to developers of software radios to ensure that the functionality needed are developed. Key issues that need to be developed for software radios include:

Radiation Tolerance. The digital signal devices used in software radios are susceptible to single-event-upsets (SEUs) and single-even latchup (SEL) in the presence of radiation. Methods to overcome these problems include radiation tolerant devices and architectures that use redundancy, but they are not fully developed for the space environment.

Power Consumption. The digital signal devices, especially microprocessors, used in software radios often require significant power, relative to available resources. Finding low-power approaches are required in the Mars environment.

Standard Approaches & Interfaces. The development of software radios is still quite new, so standards approaches are not yet defined. The evolution of software radios can be greatly enhanced with standard architectures and interfaces.

Summary: The reconfigurable software radio represents the logical evolution from hardware specific communications solutions. Software radios provide functionality that can be used to support new approaches to science missions at Mars, such as sensor webs. Scientists and planners should consider the future evolution of these flexible and powerful telecommunication devices when designing future missions to Mars.

Task Adaptive Walking Robots for Mars Surface Exploration Terry Huntsberger, Gregory Hickey, Brett Kennedy, and Hrand Aghazarian, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109-8099. (Terry.Huntsberger@jpl.nasa.gov)

Introduction: There are exciting opportunities for robot science that lie beyond the reach of current manipulators, rovers, balloons, penetrators, etc. Examples include mobile explorations of the densely cratered Mars highlands, of asteroids, and of moons. These sites are believed to be rich in geologic history and mineralogical detail, but are difficult to robotically access and sample. The surface terrains are rough and changeable, with variable porosity and dust layering; and the small bodies present further challenges of low-temperature, micro-gravity environments. Even the more benign areas of Mars are highly variegated in character (>VL2 rock densities), presenting significant risk to conventional rovers. The development of compact walking robots would have applications to the current mission set for Mars surface exploration, as well as enabling future Mars Outpost missions, asteroid rendezvous missions for the Solar System Exploration Program (SSE) and the mechanical assembly/inspection of large space platforms for the Human Exploration and Development of Spaces (HEDS).

The current mission set for Mars Outpost missions are planned beginning for the 2007 Mars launch opportunity. This requires that autonomous robotic explorers need to be developed to a high TRL level by 2004. Technology infrastructure for these robotic colonies—e.g., manned Martian habitats and/or wide-ranging robotic exploration of the Martian surface--assumes a capability of fielding multiple, robustly interacting robots. Activities at such "planetary outposts" will include deployment and servicing of power systems and ISRU generators, construction of beaconed roadways, and site preparation for, and deployment of, manned habitat modules. In general, NASA studies show the concept of precursor robotic missions to Mars using teams of multiple cooperating robots, and their sustaining presence in partnership with later manned missions, to be a cost-and-time effective alternative to purely human deployment of a manned habitat [1],[2].

Key to the concepts of self-sustaining robotic colonies and permanent deep-space robotic infrastructures is the need for flexible control systems for multiple cooperative robots that possess task adaptive properties, coupled with an integrated mechanical design for adaptive visual sensing and robot lifetime extension through self-repair or replacement of worn-out and/or broken instruments. These instruments could be mechanical tools needed for surface construction/maintenance operations, as well as scientific instruments needed for the assistance of humans in surface science operations. Another aspect of permanent presence is the utilization of local power generation facilities such as photovoltaic (PV) tent arrays or ISRU units for recharging onboard batteries or refueling operations.

Current mobility configurations for Mars surface exploration have emphasized wheeled robotic platforms, where mechanical manipulation is conducted using robotic arms and end effectors. This technology provides a stable and efficient platform, but is not likely to meet all of the needs of mechanical assembly and operations in planned Mars outpost applications. Most of the walking robotic systems emphasize mobility in cooperation with autonomous navigation (example: Dante, Ambler, Attila, Hannibal, Boadicia). For these systems that do include manipulation capability, it is integrated through separate mechanical arms attached to the platform. These tend to be large, heavy systems.

Autonomous mechanical manipulation and mobility are core requirements for any robotics system involved in construction, assembly, inspection or maintenance. In order for a single platform to be multifunctional, it must have the capability to be task adaptive (i.e. autonomously changing the tool/visual sensing configuration for a specific task). Autonomous mechanical manipulation and

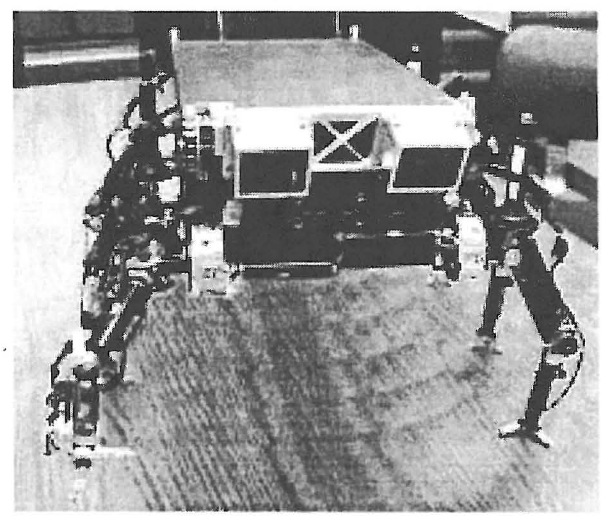


Figure 1: Six legged robotic platform LEMUR shown in a 5-point stance with active gripper extended.

mobility are core requirements for any robotics system involved in construction, assembly, inspection or maintenance.

In order for single platform to be multifunctional, it must have the capability to be task adaptive (i.e. autonomously changing the tool/visual sensing configuration for a specific task). The LEMUR (Legged Excursion Mechanical Utility Robot) platform shown in **Figure 1** is particularly adaptable. LEMUR is representative of a new class of autonomous n-pod walkers being developed at JPL under the Space Solar Power Program. It has a lightweight structural design achieved through the use of high modulus graphite/cyanate composites. It has multifunctional tools and manipulation capability for inspection and mechanical operations. The two mechanical tools currently included in the system are shown in **Figure 2**. These are a miniature grappling foot and a mechanical rotary tool.

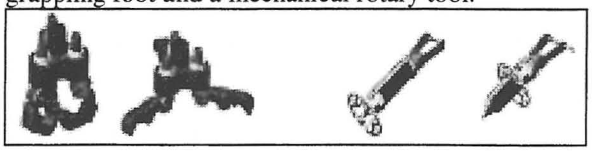


Figure 2: LEMUR mechanical tools - grappling foot (left), rotary tool (right).

The mobility layout is such that it can support itself on any three of the rear four legs, allowing the front two legs to be used as manipulators. An alternative leg layout is shown in **Figure 3**. To extend this to a reconfigurable system, the elbow joints for the front two legs are designed to allow the interchanging of manipulative tools or science instruments. These tools or instruments would be maintained in either a tool cache that is integrated into the primary structure, or a separate remote location. This reconfiguration can be extended to each of the individual legs to allow remote sensing, or cooperative repair and assembly operations.

Ongoing work at JPL includes the development of: (1) autonomous task-based change-out of tools or science instruments, (2) an adaptive, variable baseline and vergence stereovision system, and (3) autonomous onboard battery recharge from an existing, external power source. These capabilities will be integrated into the Control Architecture for Multi-Robot Planetary Outposts (CAMPOUT) that is currently being developed under the Planetary Surface Robot Work Crew task in the 632 program at JPL [3].

References:

[1] Hoffman & Kaplan (1997) Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA Lyndon B. Johnson Space Center, Houston, TX.. [2] Drake (1998) Reference Mission Version 3.0 Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA Lyndon B. Johnson Space Center, Houston, TX. [3] Huntsberger, et al. (2000) Robotic Precursor Missions for Mars Manned Habitats, this Vol.

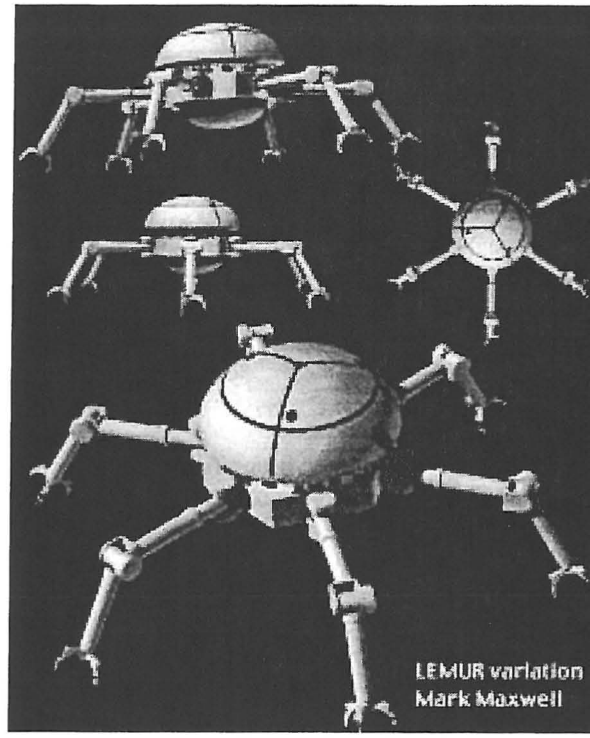


Figure 3: Alternate leg layout based on a hexagonal body

Robotic Precursor Missions for Mars Manned Habitats Terry Huntsberger, Paolo Pirjanian, Paul S. Schenker, Ashitey Trebi-Ollennu, Hari Das, Sajay Joshi, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, 91109-8099. (Terry.Huntsberger@jpl.nasa.gov)

Introduction: Infrastructure support for robotic colonies, manned Mars habitat, and/or robotic exploration of planetary surfaces will need to rely on the field deployment of multiple robust robots. This support includes such tasks as the deployment and servicing of power systems and ISRU generators, construction of beaconed roadways, and the site preparation and deployment of manned habitat modules. The current level of autonomy of planetary rovers such as Sojourner will need to be greatly enhanced for these types of operations. In addition, single robotic platforms will not be capable of complicated construction scenarios. Precursor robotic missions to Mars that involve teams of multiple cooperating robots to accomplish some of these tasks is a cost effective solution to the possible long timeline necessary for the deployment of a manned habitat.

Ongoing work at JPL under the Mars Outpost Program in the area of robot colonies is investigating many of the technology developments necessary for such an ambitious undertaking. Some of the issues that are being addressed include behavior-based control systems for multiple cooperating robots (CAMPOUT), development of autonomous robotic systems for the rescue/repair of trapped or disabled robots, and the design and development of robotic platforms for construction tasks such as material transport and surface clearing.

There are a number of robotics requirements that will need to be addressed before the arrival of the manned missions. These include both the precursor tasks as well as the needs for a sustained robotic presence on the planetary surface. Among the baseline robotics requirements (not necessarily exhaustive or in order of importance):

- Load transportation and handling
- Solar power system deployment
- Terrain conditioning and site preparation
- Infrastructure servicing and repair
- Object manipulation and handling
- ISRU plant deployment
- Internal habitat servicing

In this talk we will concentrate on the first and second points since these are key to habitat deployment.

Load and Transport: The transportation requirements are for those operations in which load or cargo is moved from one place to another. The requirements are measured in terms of force to be applied in carrying the weight, the distance to be moved, and the total work to be done. To get a first-order estimate, the main parameters needed are the masses of the main components or assemblies to be moved, as well as the distance between the initial load location and its destination after the transportation maneuver occurs. The following mass allocation shown in Table 1 is assumed for an illustrative outpost scenario [1], [2].

Table 1: Mass/work assessment for robotic precursor tasks related to a manned Mars habitat

Element of Sub-Assembly	**Mass (kg)**	**Horizontal Load Travel (meters)**	**Vertical Load Travel (meters)**	**Total Mechanical Work (Nt-m)**
Power System	3,500	200	5	2,810,000
Habitat	1000	100	5	430,000
Science Station	500	100	5	210,000
Communication Station	500	100	5	210,000
Landing Pad Infrastructure	1000	100	5	430,000
Other	2000	100	5	860,000
Total	8,500	700	30	4,950,000

From this table it is possible to conclude that the robotic transportation requirements implied by the Mars Reference Mission [1], [2] would require that the robotic capabilities in load transportation be increased over two orders of magnitude from those achieved in the Sojourner mission and a least an order of magnitude over that likely to be achieved for the sample return rover in the Athena 2003,2005 rover mission. The "Other" category in Table 1 represents all of the tasks that are not directly attributable to a specific construction project (e.g. general site cleanup). The power system deployment requirements appear to be by far the most challenging

Solar Power System Deployment: The power needs for human surface operations are substantial. Power source requirements of the order of (100+ kWe) are anticipated. Of this, about 30 kW are needed for habitation, 30-60 kW are needed for regenerative life support, and 50 kW are needed for in-situ resource utilization. A power generator of about 12-14 tonnes, or multiple power generators of about 5 tonnes each, may be needed. Alternatively, solar power arrays of about 5000 square meters minimum are needed with present technology. The advantages of the solar PV tent arrays include modularity, relatively low overall mass (3.5 tonne), and political/environmental safety.

Deployment of such a power system must be performed before the human exploration of Mars can begin. Setting up a power system is a mandatory robotic task, due to the physical limitations of the crew after an extended period of zero-G conditions. Assuming as an example a large, modular PV tent option for the power system, the required operations are as follows. The individual tent boxes must be off-loaded from the container storage unit (CSU) and moved to a cleared area 100 to 200 meters from the base. The PV tents then have to be deployed. High voltage (2-5 kV) distribution lines as well as monitoring and control lines must be set up.

We have recently started an investigation into the robotic needs for the deployment of a modular solar PV tent array such as that specified by Colozza [3]. Colozza's study demonstrated that a nearly constant power profile can be realized by a tent array using a blanket of standard silicon PV cells. In addition, atmospheric dust deposition is minimized due to the steep angle of repose (60 degrees) of the PV blankets. The study also included an examination of the relevant wind force upon the array. Such a PV tent array would be difficult to deploy using a solitary robot, since the modules are 5 meters long and would represent a considerable challenge for precision placement.

Current efforts at JPL are investigating the coordinated transport of the PV tent array units to the deployment site. This task is currently funded under the Cross Enterprise Technology and Development 632 Program. A half-scale container (250cm X 12.5cm X 12.5cm) is being used for the experiments. We have designed a prototype construction class rover called CREWbot (Cooperative Robot for Exploration and Work), shown in **Figure 1**.

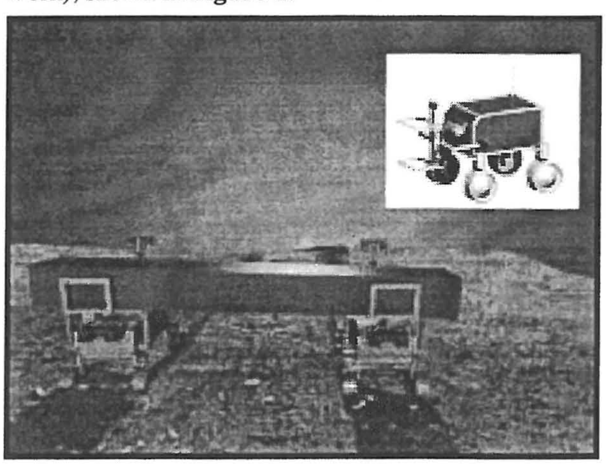


Figure 1: CREWbot concept currently under construction at JPL, with coordinated transport of PV tent container.

References:

[1] Hoffman & Kaplan (1997) "Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team", NASA Lyndon B. Johnson Space Center, Houston, TX. [2] Drake (1998) "Reference Mission Version 3.0 Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team", NASA Lyndon B. Johnson Space Center, Houston, TX. [3] Colozza (1991) "Design and optimization of a self-deploying PV tent array", NASA CR187119, Lewis Research Center Group, Brook Park, OH.

CRSIM - a Combined Remote Imager and Spectrometer for Mars. N. R. Izenberg, S. L. Murchie, D. E. Fort, The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723 (email: noam.izenberg@jhuapl.edu).

Introduction: The requirements for the visble-NIR spectrometer for NASA's proposed Mars-2003 orbiter focus on detection of the mineralogic signature of past aqueous environments. These include 100 m/pixel or better spatial resolution, the capability of measuring 1% of the planet per Mars year, covering a wavelength range of 400-2600 nm with high signal-to-noise ratio (SNR) (>300-400) and spectral resolution (10 nm/channel at critical wavelengths), and the ability to account for atmospheric effects on surface spectra. CRISM, the Combined Remote Imager and Spectrometer for Mars, meets and exceeds all these requirements.

CRISM Summary: CRISM is a dual visible multispectral imager and near-infrared (NIR) imaging spectrometer with common fore optics, and a high-precision scan mirror designed to scan the fields-of-view slowly across a target while overflying it at high velocity. To achieve its objective of measuring the mineralogic signatures of past aqueous environments, instrument design is only slightly modified from the CRISP instrument on CONTOUR. The spectral range is expanded, and the scan mirror and electonics have been configured to interface with the Mars-2003 orbiter. CRSM's multispectral CCD camera covers 10 spectral bands at 400-800 nm. Its NIR grating spectrometer images a slit onto a cryogenically cooled HgCdTe array. 256 spectral channels cover the wavelength ranges 800-2600 nm at 9 nm/channel and 2600-3000 nm at 26 nm/channel.

Performance: During a baseline data acquisition sequence (Figure 1), CRISM would spectrally map a target region of approximately 10 x 25 km at 30-40 m/pixel in visible wavelengths (400-800 nm) and 65-85 m/pixel in infrared wavelengths (800-3000 nm). Before and after flying over the site, it would acquire monochrome 10 m/pixel images at complementary stereo geometries. Following the flyover, it would also remeasure through a longer atmospheric path length the part of the target first viewed at nadir.

These data meet or exceed all of the performance requirements for the Mars-2003 orbiter spectrometer as defined by the Mars 2003 Opportunity Science Instrument Definition Team (SIDT) [1]. Spatial resolution exceeds the required 100 m/pixel, and approaches the preferred resolution of 40 m/pixel. CRISM can accomplish the required 1% coverage of the planet during 1 Martian year by taking as few as one observation per orbit, well within the operational lifetime of the cryogenic cooler.

Wavelength range and SNR meet the requirements for characterization of weak to moderate strength absorptions due to ferric and ferrous minerals, carbonates, and hydroxylated minerals (Figure 2). At the baseline exposure time, SNR exceeds 400 at 600-2400 nm and 300 at 500-2600 nm. A lower SNR of 50-100 inside the broad 3-μm absorption is adequate for measuring bound H_2O, whose absorption strength varies typically in the range 50-65% [2, 3].

Spectral resolution meets the requirements for distinguishing compositionally related minerals formed in aqueous environments. The 9 nm/channel resolution at NIR wavelengths can discriminate positions of 1-μm bands of various Fe minerals and the shapes of absorptions due to hydroxylated minerals at ~1400 nm and 2200-2400 nm. Visible wavelengths are covered using a filter wheel and CCD imager. The decision to cover visible wavelengths in this manner was made during Phase A/B of CONTOUR, when a trade study by the science team showed that the spectral resolution required to characterize Fe absorptions at visible wavelengths is less than is required for narrow NIR absorptions. The resulting less demanding spectral resolution requirement allows higher spatial resolution visible-wavelength data to be acquired at high SNR. Figure 3 shows extended visible-wavelength spectra of Mars analog minerals resampled into CRISM bandpasses, ~9 nm/channel at >800 nm and imager filters nominally at 440, 480, 530, 580, 610, 650, 680, 710, 740, and 770 nm. The visible-wavelength multispectral approach samples key absorptions at ~530 and ~650 nm sufficiently to distinguish spectrally similar, compositionally related minerals such as hematite (α-Fe_2O_3) and maghemite (γ-Fe_2O_3) or goethite (α-FeOOH) and lepidocrocite (γ-FeOOH).

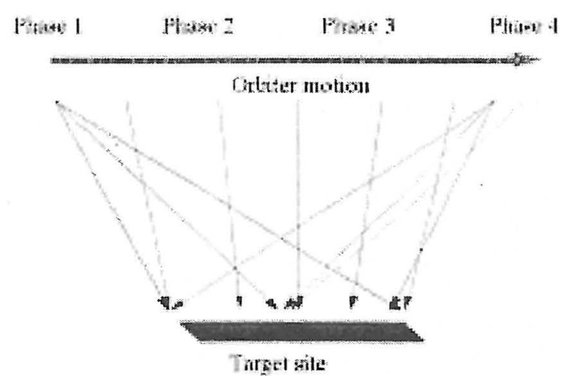


Figure 1. Nominal CRSIM data acquisition sequence from the Mars 2003 orbiter. Phase 1: incoming stereo; Phase 2: low emission angle spectral imaging; Phase 3: outgoing stereo; Phase 4: high emission angle spectral imaging.

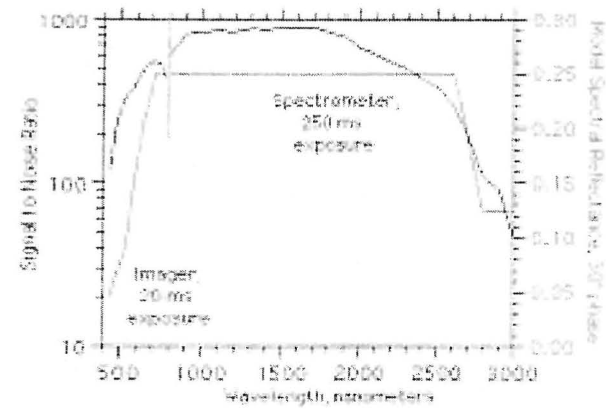


Figure 2. SNR of typical CRISM data at Mars, assuming a spectral reflectance model typical of a dark red region (Lunae Planum) observed from a 2 PM orbit.

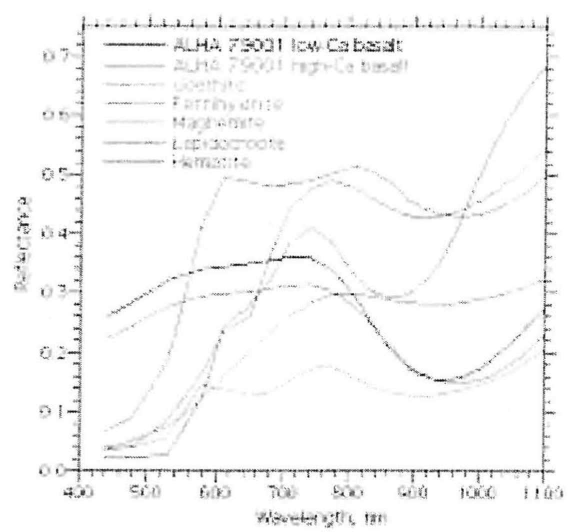


Figure 3. Extended visible wavelength spectra of plausible Mars surface minerals, sampled to CRISM wavelengths. CRISM clearly distinguishes the compositionally related ferric minerals.

The SIDT required an experimental approach to account for the effects of atmospheric opacity on the spectra of surface materials. Doing so requires two types of measurements. The first measurement is atmospheric opacity. Ideally this is measured separately at each target site, because aerosol opacity varies spatially. CRISM determines atmospheric opacity by measuring a part of each site twice, under practically identical illumination and meteorological conditions (<2 min apart), but at different emission angles and hence atmospheric path lengths.

The second measurement is of the relative amounts of illumination by solar irradiance and by scattered atmospheric radiance. Differences in the relative amounts of the two types of illumination were observed to cause dramatic changes in the spectral properties of irregular objects at the Mars Pathfinder landing site [4]. This effect will also be important at sites of the type measured by CRISM at high spatial resolution. Geologic formations possibly exhibiting mineralogic signatures of past aqueous environments are likely to be topographically rough, and many will be at mid- to high latitudes and thus illuminated obliquely. These factors will cause spectral variations due to differences in illumination, at the scale of spatial pixels. CRISM's measurement of atmospheric opacity will be useful in estimating attenuation of solar irradiance at oblique illumination as well as the spectrum of sky radiance. Photometric correction of surface spectra using this knowledge also requires knowledge of topographic slopes near the scale of the spectral data. This is provided by stereo imaging. The vertical accuracy of the DEM derived from these data will be kRH/B [5], where R is the effective spatial resolution of the image data (10 m), B/H is the base to height ratio of the stereo images (~1.2), and k is the accuracy of coregistration of the data. k can be as low as 0.2 for data with an SNR near 100; this is attained in the imager filters near 700 nm using a 10-12 ms exposure time. CRISM's stereo imaging provides a theoretical vertical resolution of ~2 m so that, at the scale of the spectral data, incidence and emission angles can be estimated with a theoretical accuracy of ~3°.

As a bonus, CRISM's stereo imaging provides an improved capability to determine the geologic context of spectral measurements of the surface. MOC-like (1-2 m/pixel) and MARCI-like (40 m/pixel) imagers are both included in the proposed orbiter payload. These differ by more than an order of magnitude in spatial resolution. Such a difference in resolution will cause problems in relating features seen in the two data sets. CRSIM's 10 m/pixel imaging capability bridges this gap, and thus improves the interpretibility of MOC images of a target site of spectral measurements.

Flexibility in CRISM's design allows instrument performance to be further optimized. For example, coverage of the data could be doubled by operating the NIR detector at its full speed of 6 Hz. Alternatively, a different NIR pixel-binning strategy could be used to cover a smaller target area with spatial resolution increased to the preferred 40 m/pixel, while maintaining SNR over the required wavelength range at >200.

References:

[1] Garvin, J. (2000). Report of the Mars 2003 Opportunity SIDT, Oral Presentation. [2] Murchie, S. et al. (1993) *Icarus 105*, 454-468. [3] Bell, J. (1996). In *Mineral Spectroscopy* pp. 359-380. The Geochem. Soc., Spec.Pub. No. 5. [4] Smith, P., *et al.* (1997) *Science 278*, 1758-1765. [5] Cook A. *et al.* (1996) Planet. Space Science 44, 1135-1148.

CONSTRUCTING A VIABLE MARS ARCHITECTURE: "PLANS ARE WORTHLESS, PLANNING IS ESSENTIAL". Bruce M. Jakosky, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392; email bruce.jakosky@lasp.colorado.edu.

We clearly have not been able to construct a viable Mars mission architecture. Two reasons are (i) we describe a complete mission suite that exactly utilizes available resources, without building in adequate flexibility to respond to scientific or technical issues, and (ii) decision points on imminent missions are coming faster than our ability to converge on an architecture, so that we are at risk of flying missions that do not fit into the broader goals of the program. I would like to propose an approach to constructing an architecture that will allow us to move steadily toward achieving the science goals. The basic thrust is that we need to develop the capabilities needed in a stepwise manner, maintain flexibility to deal with setbacks by not committing to missions too far in advance, and ensure that the missions flown fit in a straightforward and appropriate way into the overall program goals.

1) What do we want to accomplish with the Mars Surveyor program over the next decade?

Most people are in agreement on this issue, that the tripartite goals are to understand martian life (or its absence), climate, and resources, with life being the more equal of equals and water being the unifying theme. There also is a growing consensus that no single measurement, mission, or returned sample is likely to answer these questions, and that a multi-pronged approach will be necessary. In particular, each measurement can be properly interpreted only in the much broader context of Mars as a planet; this requires a wide suite of missions and measurements. In particular, it is likely that significant progress can be made by a combination of:

- Continued global reconnaissance to determine the composition of surface materials, their global distribution, and their relationship to surface geology.
- Detailed measurements of the atmosphere, both locally (e.g., over the polar caps) and globally, in order to understand the atmospheric dynamics, the current seasonal cycles, and the relationship to climate and climate change.
- Global and local geophysical reconnaissance, including measurements of heat flow, seismic activity and internal structure, and near-surface regolith and crustal structure.
- *In situ* analysis at specific sites, in order to verify the conclusions from remote-sensing measurements and to understand their history (e.g., the history of paleolakes or the nature of hydrothermal systems, potential for organics, occurrence of near-surface liquid water, nature of polar caps).
- Return of rock and soil samples from multiple sites where there is a clear relevance of the samples to geological history, volatile and climate history, and potential for life.
- Return of an unaltered sample of the present-day martian atmosphere, separate from rock and soil samples, in order to address the volatile inventory and history.

2) Is there a single set of missions that we can define today that will accomplish this?

The answer is yes only for the glib or superficial. We could easily define a single suite of missions. However, there is no agreement as to what measurements are required in order to allow selection of landing sites or samples, whether early or planned-in-more-detail sample return is a better approach, or how to trade off lander safety with science return. In addition, the technical issues are substantial at each phase of the program; as we have seen, well-defined programs become obsolete when mission failures occur.

A better approach would be to define a set of scientific and technical milestones that, when finally achieved, will allow us to achieve the science goals, and then work toward completing the milestones in a stepwise manner. Each mission would build on the previous missions and extended the results, add capability that is needed in order to achieve the final goal, and be designed to maintain flexibility in order to respond to technical problems or setbacks.

3) What technical and scientific milestones will allow us to meet these goals?

Scientific milestones:

- Determining the composition of the surface, at both kilometer and 100 m spatial resolution, to understand the relationship between local and global surface composition and geological history.
- Determining enough about the history of liquid water to allow intelligent site selection; this can be done by identifying sites of ancient surface water activity, ancient or recent hydrothermal activity or hot or cold springs or seeps, and near-surface groundwater or ground ice, based on a wide variety of remote measurements.
- Determining what types of samples collected from what locations will allow us to make the most-rapid progress (i.e., *in situ* analysis of rock and soil composition at relevant sites, possible early sample return).

Technical milestones:

- Ability to land safely on the surface at a geologically safe site.
- Ability to land safely on the surface at a geologically exciting (i.e., potentially hazardous) site.
- Identifying the hazard level of potential landing sites and integrating this with spacecraft capability analysis.
- Ability to analyze samples *in situ* as necessary, to collect them, and to package them for return to Earth.

- Ability to launch a return container from the surface of Mars, get it back to Earth, and recover it.
- Ability to deal with samples returned to Earth (i.e., sample handling and biohazard facility).

4) How do we maintain flexibility to accomplish these milestones?

- We should design a suite of missions that will accomplish these specific milestones, thereby building toward sample return missions that can address our overall science goals.
- We should maintain flexibility to deal with mission failures or return of scientific or technical information that would cause a change in plans (i.e., take to heart Eisenhower's comment about planning being essential but plans being useless); this can be done in a program that builds stepwise toward the final goals and does not commit to missions a decade out.
- We should recognize that the program will require more than, say, three missions to complete, that the speed of progress will depend on the available funding, and that we will not know up front how many missions or years it will take to achieve the goals.
- We should insist that missions be carried out with adequate funding to allow the possibility of success.

PALOMA: In-Situ Measurement of the Isotopic Composition of Mars Atmosphere. A. Jambon[1], E. Quemerais[2], E. Chassefière[3], J.J. Berthelier[4], P. Agrinier[1], P. Cartigny[1], M. Javoy[1], M. Moreira[5], J.-F. Pineau[6], J.-C.Sabroux[7], P. Sarda[8]. [1]Laboratoire de Physico-chimie des Fluides Géologiques , Université P. et M. Curie and IPG Paris, 75252 Paris (France), [2]Service d'Aeronomie (IPSL, Paris), [3]Laboratoire de Météorologie Dynamique (IPSL, Paris), [4]Centre d'Etudes Terrestres et Planétaires (IPSL, Paris), [5]Laboratoire de Géo et Cosmochimie (IPG, Paris), [6]Private Company (St Sylvestre), [7]Institut de Protection et de Sureté Nucleaire (IPSN,Gif-sur-Yvette), [8]Groupe de Géochimie des Gaz Rares (Paris XI-Orsay)

Scientific objectives : Scientific objectives for an atmospheric analysis of Mars are presented in the DREAM project [1]. Among the informations presently available [2-5] most are fragmentary or limited in their precision for both major element (H, C, O, N) and noble gas isotopes. These data are necessary for the understanding and modelling of Mars atmospheric formation and evolution , and consequently for other planets, particularly the Earth.

To fulfill the above requirements, two approaches can be envisonned: 1) analysis of a returned sample (DREAM project [1]) or 2) in situ analysis, e.g. PALOMA project presented here.

Among the advantages of in situ analysis, we notice: the minimal terrestrial contamination, the unlimited availability of gas to be analyzed and the possibility of multiple analyses (replicates, day-night...). Difficulties specific to in situ analyses are of a very different kind to thoses of returned samples. In situ analysis could also be viewed as a preparation to future analysis of returned samples. Finally, some of the measurements will not be possible on Earth: for instance, radon and its short lived decay products, will provide complementary information to ^{4}He analysis and can only be obtained in situ, independently of analytical capabilities. More specifically:

Noble gas isotopes: He abundance and isotopes are important for solar input and continuous outgassing.

Ne : ^{20}Ne/^{22}Ne and ^{21}Ne/^{22}Ne are characteristics of the source of the atmosphere (planetary vs solar). Mass fractionating escape may also have played a role.

Ar: ^{40}Ar, radiogenic product of ^{40}K, documents the continuous outgassing as the primordial ^{40}Ar/^{36}Ar is close to zero.

Kr is devoid of significant radiogenic/nucleogenic isotopes. Its fractionated pattern relative to the solar value is of importance to trace a possible mass fractionating escape.

Xe: Its fractionated pattern relative to the terrestrial atmosphere (strongly constrained by the light isotopes), and the abundance of radiogenic isotopes, daughters of short and long-lived isotopes (mostly ^{129}Xe, ^{134}Xe and ^{136}Xe) have to be determined catastrophic

In addition the relative abundance of all noble gases compared to the solar or terrestrial atmosphere is important for comparative planetology.

Rn isotopes and their Decay Products (RnDP) : The study of the various isotopic ratio between RnDP and Rn (i.e. ^{210}Po/^{222}Rn) is expected to provide some information on the instantaneous outgassing (diffuse or localized remaining volcanic activity and natural radioactivity of martian soils)) and will also be compared with ^{4}He (study of the origin of ^{4}He). Equilibrium ratio (i.e. ^{214}Po/^{222}Rn. or ^{220}Rn/^{222}Rn) are expected to provide also complementary information on the atmospheric circulation.

The isotopic compositions of H, C and N are highly variable among different objects of the solar system. They may also have been secondarily altered (e.g. escape) to different extents. Are the rocks in isotopic equilibrium with the present-day atmosphere or with a former one which is now lost? Answers to these questions are important to select which evolution model is appropriate. The isotopic composition of O in CO_2 is of great importance as O is the keystone in SNC identification. Is it in equilibrium with surface rocks and under what conditions (temperature)?

A number of the aforementionned processes may have played a role in the case of the terrestrial atmospheric evolution to a different extent though. Understanding present day atmospheric composition, its evolution, catastrophic climatic events are problems which require factual constraints to be modelled appropriately. The isotopic composition of C, N, O and noble gas isotopes will provide valuable constraints to the models of atmospheric evolution.

Scientific and Technical approach : The project is to have a Mass spectrometer together with a Rn and RnDP analyser on a lander in 2005. Accurate measurement of isotopic composition of trace gases requires their separation from one another. In the course of a phase A study, the characteristics and performances of two different solutions for the MS are presently being investigated, namely a magnetic MS deriving from a classical Nier-Johnson geometry and an adapted version of a TOF MS. A hot Ti getter permits to get rid of the reactive components and cryogenic separation is necessary to separate He, Ne/ Ar / Kr / Xe. Reactive gases will be analysed after desorption from the cryoseparator. The analytical principle is as follows:

Step 1:

- Sampling 1-10 cm^3 of Mars atmosphere
- Purification of the sample using a hot Ti getter
- Separation of the noble gases in three fractions with a cryotrap (1) helium and neon, (2) argon, (3) krypton and xenon.
- Successive analysis of the three fractions with a mass spectrometer.

Step 2:

- sampling another aliquot of Mars atmosphere
- trapping CO_2 with a cryotrap for N isotope analysis.
- desorption of CO_2 and analysis of $^{18}O/^{16}O$ and $^{13}C/^{12}C$ in CO_2.
- Analysis of trace components.

Step one and two can be repeated as many times as necessary, changing the sample volume, the sampling time (day or night) and for more accurate determination. Estimate of the equipment weight is 5.5 kg, 16W for a 70 min analytical cycle.

Concerning Radon isotopes and their RnDP, they will be analysed by a spectrometric counting of α particles with a Si detector incorporated into a special detection assembly connected to a multichannel analyser. The following isotopes will be studied : (,^{220}Rn, ^{222}Rn, ^{218}Po, ^{214}Po, ^{216}Po, ^{212}Po, ^{210}Po and ^{212}Bi. Due to the long path (• 6m for the concerned energy range) of α particles in the martian atmosphere, a passive geometrically defined detection system will be suitable. The analysis will be repeated continuously, with a time schedule which will depend upon the level of pollution of the detector by plated out RnDP (due to the short half lives of the concerned isotopes, depollution can be very effective within a few hours) and upon the level of atmospheric radioactivity encountered.

Preliminary specifications: 3.2 kg and 3.3 W/5min.

References : [1] Marty B. et al. (2000) *this volume.* [2] Bogard D.D. and Garrison D.H.(1998) *GCA* 62, 1829. [3] Krasnopolsky V.A. et al (1994) *Icarus* 109, 337-351. [4] Nier A.O. and McElroy M.B. (1977) *JGR* 82, 4341-4349. [5] Owen T.et al. (1977) *JGR* 82, 4635-4639.

A BALANCED MODEL FOR EXPLORATION OF THE TERRESTRIAL PLANETS: LESSONS FROM THE LUNAR EXPERIENCE.

CAPTEM (Curation and Analysis Planning Team for Extraterrestrial Materials): B. L. Jolliff[1], L. P. Keller[2], G. J. MacPherson[3], C. R. Neal[4], D. A. Papanastassiou[5], G. Ryder[6], C. K. Shearer[7] and J. J. Papike[7], [1]Washington University, St. Louis, MO (blj@levee.wustl.edu), [2]MVA Inc., Atlanta, GA; [3]Smithsonian Institution, Washington, DC; [4]Notre Dame University, West Bend, IN; [5]Jet Propulsion Laboratory, Pasadena, CA; [6]Lunar and Planetary Institute, Houston, TX; [7] University of New Mexico, Albuquerque, NM.

The Moon is the only extraterrestrial rocky body for which we have a combination of surface-selected samples, high-resolution orbital photography (*Lunar Orbiter*), manned and robotic surface exploration (*Surveyor, Apollo, Luna*), and global compositional, mineralogical, and geophysical data (*Galileo, Clementine, Lunar Prospector*). Beginning in 1998, CAPTEM organized a series of workshops and conference sessions aimed at integrating these diverse data sets. The insights gained by bringing together scientists from the remote-sensing and sample-analysis communities have been singularly rewarding. Not least of these has been the recognition by both groups that having both kinds of data maximizes the scientific return and permits reconciling information from diverse scales and perspectives. The 20-20 hindsight of the Lunar experience thus provides important lessons; learning from mistakes as well as successes, we can derive a sensible scientific program for Mars exploration. In this abstract, we describe examples of key information from (a) in-situ geologic investigation, (b) laboratory analysis of returned samples whose geologic context and location are known, and (c) global remote sensing of mineralogy, composition, and geophysical parameters. We then show the value of integrating these diverse data sets.

In-situ geologic investigation

The *Apollo* landings, especially those that incorporated high-mobility rovers, set a standard with which to compare the capabilities of future planetary landing-site exploration. These missions enabled numerous surface experiments as well as thorough sampling of geologic diversity at the landing sites. Key surface experiments included direct measurements of surface temperature, heat flow, atmosphere, and ionizing radiation, and emplacement of seismic monitoring stations and laser ranging retroreflectors. These experiments resulted in models for internal structure, distribution of elements, and lunar orbital dynamics and evolution.

Analysis of returned samples

The laboratory analysis of *returned samples* gave exact information about rock types and lithologic diversity. Spectral reflectance can provide information about target mineralogy, but only laboratory analysis can give precise mineral compositions and, especially, the relationships of the minerals to one another (textures). Analysis of samples reveals other aspects of lithology that reflect both process and provenance. For example, lunar rocks include a range of impact-produced fragmental and annealed breccias, lithified regolith, impact-melt rocks and glasses, and volcanic glass deposits, as well as crystalline basalts and igneous rocks. The diversity of rock types may be gleaned from a reasonable number of well chosen samples. In addition to textural variety, samples reveal less abundant rock types such as, in the lunar case, dunite, felsite, monzodiorite, monzogabbro, alkali norite, alkali anorthosite, different pyroclastic glass types, and a wide variety of basalt types [1]. Minor or accessory minerals that are very important to rock petrogenesis and classification, such as silica minerals, phosphates, Fe-Ti oxides, spinels, alkali feldspar, sulfides, and Fe-metal, were only found through direct analysis of samples.

Among the most important data obtained from returned samples are radiometrically determined crystallization ages. Lunar samples revealed the 4.0–4.5 Ga age of ancient lunar-highlands crustal rocks, the 3.8–4.0 Ga age of melt rocks produced by basin impacts, and an ~3–4 Ga range for mare-basaltic volcanism. From this information, the thermal and magmatic history and evolution of the Moon were inferred, including the differentiation of the Moon and the extraction of its crust shortly after accretion. Recent tungsten isotopic studies further suggest that magma-ocean solidification was rapid, occurring within several tens of millions of years of solar system formation [2]. Determination of exposure ages for rocks whose geologic context points to a specific impact event provided a calibration of the age of surfaces associated with specific crater densities and morphologies, for example, the ~900 m.y. age of Copernicus and the ~100 m.y. age of Tycho. This calibration led to the inference that even younger basaltic surfaces may exist than those dated directly with samples.

The analysis of major, minor, trace, and isotopic elemental compositions provided specific information about the lunar bulk composition and differentiation processes. The complementary nature of trace-element contents of mare basalts and feldspathic crustal rocks revealed their petrogenetic association wherein the mafic sources for mare basalts formed as early mantle cumulates and the feldspathic crust formed as buoyant cumulates from a single magma ocean. Mare basalts formed later by partial and complex melting of the mafic cumulates. Trace-element compositions revealed the common residual-melt chemical component KREEP (rich in K, REE, P, and other incompatible elements).

The laboratory study of lunar regolith showed the effects of exposure to cosmic and solar radiation and micrometeorite bombardment, the most pervasive forms of lunar surface weathering. Surface weathering processes have produced a specific and common grain size that coats practically all other surface materials and dominates reflectance spectra, a condition that is perhaps analogous to the presence of windblown dust on the martian surface.

Remote Sensing

Earth-based telescopic study of the lunar near side and orbital satellites for regional and global remote sensing have provided context within which to interpret the lunar surface and its structure. High resolution photogeology and geomorphology coupled with elevation data have illuminated surface structures and processes that modified the crust, especially impact crater morphology and volcanic features characteristic of hot, dry, Fe-rich, and low-viscosity lavas. Global gravity maps provide information on crustal structure and the distribution of mass, for example the concentrations of mass resulting from dense mantle uplift beneath the center of many impact basins [3]. Multispectral imaging reflects numerous characteristics of the surface mixture including composition, mineralogy, and texture, and allows classification of the surface into units of like character. Reflectance spectroscopy has been used effectively to classify different basalt types, especially as they vary according to TiO_2 content [4]. Global maps of surface composition from gamma-ray and neutron spectrometry have shown a remarkable compositional asymmetry associated with the Procellarum KREEP Terrane and enhanced H concentrations in permanently shadowed regions of the lunar poles [5-7]. Magnetic fields, although very weak, are present and reflect in part effects associated with basin impacts and with the presence of a small metallic core [8].

Integration Synergy

The ability to examine global remotely sensed data sets in the context of analytical data that exist for the site-selected *Apollo* and *Luna* samples has allowed for significant advances in understanding the Moon. Three key examples of such integration are given here. First, analysis of samples has provided ground-truth calibration of remotely sensed data. Compositions of surface soils from individual landing-site sample stations have been used to calibrate measures of FeO and TiO_2 using the ferrous absorption near 1 μm and the UV/VIS slope, respectively [9]. Understanding the geology and compositional variations at a landing site, tied to known rock and soil compositions, permits extrapolation of compositions for calibration of low spatial-resolution data, thus, *Lunar Prospector* gamma-ray data for Th have been calibrated according to thorium concentrations of landing site soils extrapolated to regional scale to match the spatial resolution of remote data [10].

A second example is the extension of what is known from areas of detailed surface investigation to areas that have not been investigated in detail, or to regional or global scales. A prime example is the calibrated global Th map, which is being used to develop increasingly accurate estimates of bulk Moon Th content [11, 12] and which has defined the profound concentration of Th and other heat-producing elements (known from inter-element correlations measured in samples) in the Procellarum KREEP Terrane. The distribution of Th reflects a global asymmetry that corresponds to the abundance and persistence of volcanic resurfacing, the character of intrusive igneous suites, and thermal evolution. Current research is focusing on dynamical processes that could have produced such a singular mode of thermal and magmatic evolution [13].

A final example relates to the direct study of surface materials that are altered by exposure to ionizing radiation and micrometeorite impact, and that most influence remote spectral reflectance measurements. The discovery of agglutinates and the careful quantification of impact-fused glass in different soil size fractions, coupled with the characterization of submicron Fe metal in altered and accretionary rims on soil grains has melded with a theoretical understanding of the effects of these components and led to a convergence of theoretical prediction and observed reflectance properties [14–16]. Furthermore, knowing why and how soil alteration affects reflectance spectra is *the enabling step* to lead to a real understanding of the lithologic components of soils from their remote spectra and ultimately to recover information about source rock types.

Remote-sensing studies of planetary surfaces, especially reflectance spectroscopy and gamma ray spectroscopy, are crucial to providing truly global coverage of chemical and mineralogic properties. *In situ* geologic exploration provides necessary context. Sample return provides ground truth for rock and soil chemistry, absolute ages with high precision, and "calibration" of remote-sensing techniques, especially where soil is a large but poorly understood component. All three of these elements are critical for planetary exploration. Mars is a very different body than the Moon, but the goal should be for all three elements to proceed in parallel. The presence of windblown dust and an unknown degree of surface weathering mandate early sample return to correctly interpret remotely sensed data. The lesson from Apollo is that carefully sited sample return with well-documented geologic context and capturing diversity within that context are key to maximizing the integration of sample and remotely sensed information.

References: [1] Papike et al. (1998) *RIM, Vol. 36*; [2] Shearer & Newsom (2000) W-Hf isotope abundances and the early origin and evolution of the Earth-Moon system. *Geochim. Cosmochim. Acta* (in press). [3] Wieczorek & Phillips (1999) *Icarus* **139**, 246-259. [4] Giguere et al. (2000) *Met. Planet. Sci.* **35**, 193-200. [5] Lawrence et al. (1999) *Geophys. Res. Lett.* **26**, 2681-2684. [6] Elphic et al. (1998) *Science* **281**, 1493-1496. [7] Feldman et al. (2000) *J. Geophys. Res.* **105**, 4175-4195. [8] Hood et al. (1999) *Geophys. Res. Lett.* **26**, 2327-2330. [9] Lucey et al. (1998) *J. Geophys. Res.* **103**, 3679-3699. [10] Gillis et al. (2000) *LPSC XXXI*, #2058. [11] Jolliff et al. (2000) *LPSC XXXI*, #1763. [12] Warren (2000) *LPSC XXXI*, #2082. [13] Zhong et al. (2000) *Earth Planet. Sci. Lett.* **177**, 131-140. [14] Hapke (1998) *New Views Workshop*, LPI. [15] Keller et al. (1999) *New Views II Workshop*, LPI. [16] Taylor et al. (1999) *New Views II Workshop*, LPI.

REMOTELY-SENSED GEOLOGY FROM LANDER-BASED TO ORBITAL PERSPECTIVES: RESULTS OF FIDO ROVER FIELD TESTS.

B. Jolliff[1], J. Moersch[2], A. Knoll[3], R. Morris[4], R. Arvidson[1], M. Gilmore[5], R. Greeley[6], K. Herkenhoff[7], H. McSween[2], and S. Squyres[8]. [1]Dept. Earth & Planetary Sci., Campus Box 1169, Washington University, St. Louis, MO 63130 (blj@levee.wustl.edu). [2]University of Tennessee, [3]Harvard University, [4]Johnson Space Center, [5]Jet Propulsion Lab, [6]Arizona State University, [7]US Geological Survey, [8]Cornell University.

Tests of the FIDO (Field Integration Design and Operations) rover and Athena-like operational scenarios were conducted May 7–16, 2000 [1]. A group located at the Jet Propulsion Lab, Pasadena, CA, formed the Core Operations Team (COT) that designed experiments and command sequences while another team tracked, maintained, and secured the rover in the field. The COT had no knowledge of the specific field location, thus the tests were done "blind." In addition to FIDO rover instrumentation, the COT had access to LANDSAT 7, TIMS, and AVIRIS regional coverage and color descent images. Using data from the FIDO instruments, primarily a color microscopic imager (CMI), infrared point spectrometer (IPS; 1.5–2.4 μm), and a three-color stereo panoramic camera (Pancam), the COT correlated lithologic features (mineralogy, rock types) from the simulated landing site to a regional scale. The May test results provide an example of how to relate site geology from landed rover investigations to the regional geology using remote sensing. The capability to relate mineralogic signatures using the point IR spectrometer to remotely sensed, multispectral or hyperspectral data proved to be key to integration of the in-situ and remote data. This exercise demonstrated the potential synergy between lander-based and orbital data, and highlighted the need to investigate a landing site in detail and at multiple scales.

Initial observations included a 3-color mosaic made with the Pancam as shown in the Fig. 1. The overall scene was examined to establish present-day geologic context, which is a rocky desert regolith, possibly a debris flow or slump deposit, separated from a steep escarpment by an arroyo (Fig. 1), and to locate significant features and plan traverses. Individual wedges were examined at full resolution and in stereo to select rock targets for detailed investigation with the IPS, CMI, and the Mini-Corer.

An example of a rock selected for further investigation is also shown in Fig. 1; it has a spotted appearance and is bright at 750 nm (green in the image; true color ~ red). Point spectra from this rock were either featureless and dark or were indicative of organic matter. The microscopic imager revealed the spots to be lichens. Parts of this rock and others that were not covered by lichens revealed the reddish, fine-grained lithology to be oxidized basalt whose source is likely a young basalt flow that forms a capping rock at the top of the escarpment.

Integrating data over diverse scales

The general approach to our investigations was to examine rocks up close using all of the rover instruments, then use the color Pancam and the IPS to interrogate soils, rocks, and outcrops that were too far or on terrain too rough to reach. We then located the region of the landing site in the high-altitude remotely sensed data and compared spectral information using ground rock/mineral identifications as a guide.

A prominent boulder lithology at the landing site was found to have a strong spectral signature of dolomite (Figs. 2, 3). On close inspection, one of these (Fig. 2) was found to have a mottled, clastic texture that indicates it was produced in an ancient tidal regime. This texture and the occurrence of cobble and pebble-sized clasts weathering out from the base of the boulder shows that it consists of coherent dolomite clasts in a soft matrix and was probably ripped up and reassembled as part of a storm deposit. This lithology reflects an ancient wet environment that would have been a likely location for microbial mats; however, the short duration of the test precluded a CMI search for fossils.

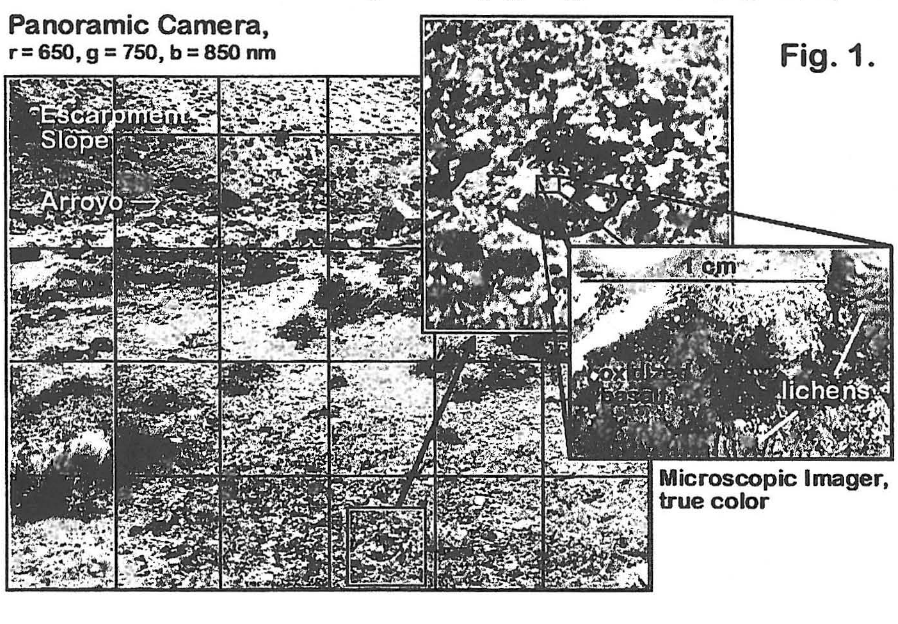


Fig. 1.

Remote geology from lander to orbital perspectives: B. Jolliff et al.

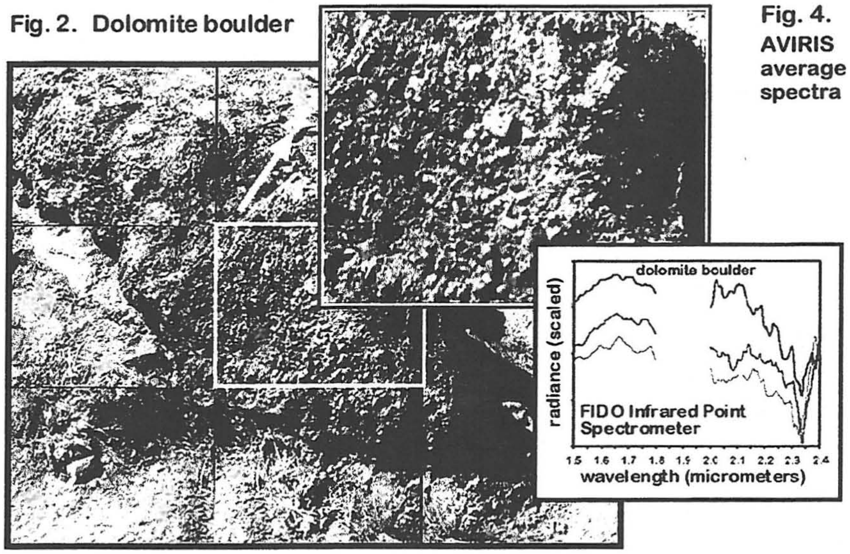


Fig. 2. Dolomite boulder

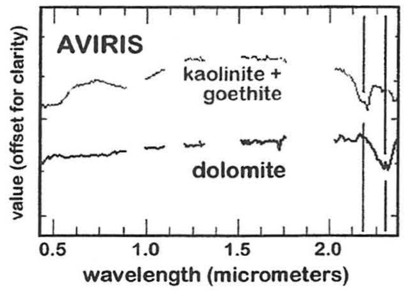
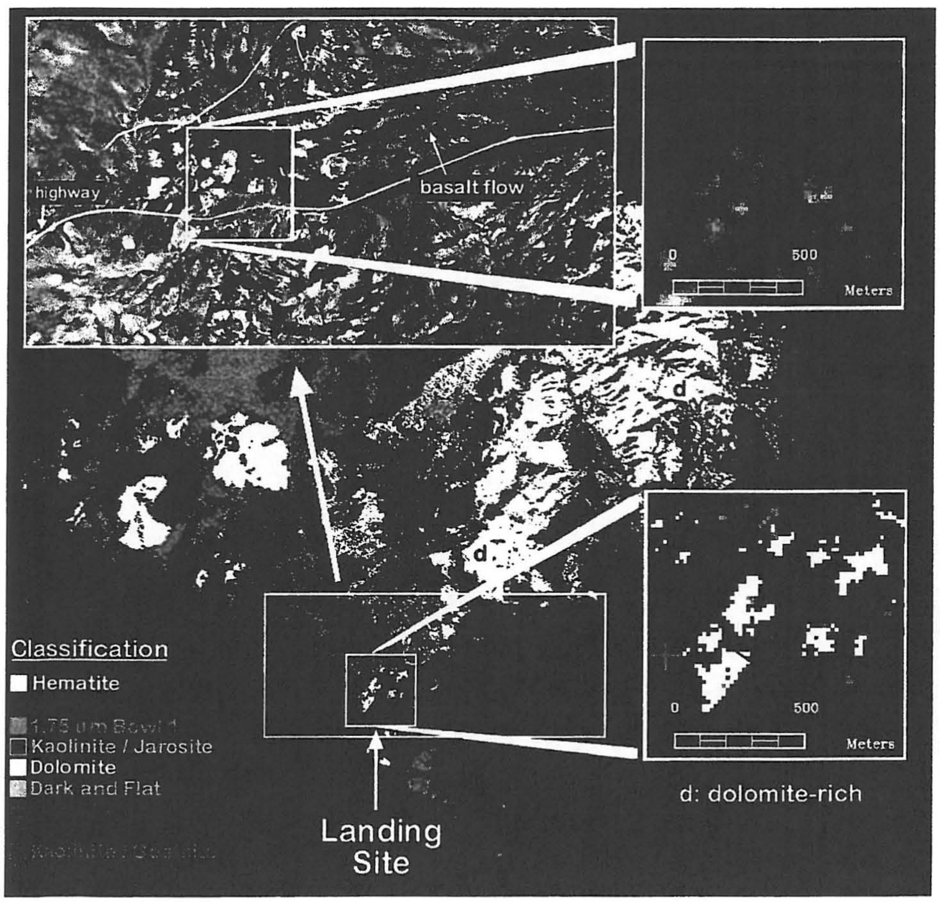


Fig. 4. AVIRIS average spectra

Using the IPS, the spectral signature of dolomite was also observed in outcrops on the steep escarpment across the arroyo. Also present at the landing site and exposed in the escarpment and stratigraphically above the dolomite-rich unit was a light-colored unit dominated by the spectral signature of kaolinite, suggesting weathering of a felsic volcanic unit.

Descent images and aerial photography were used to locate the landing site and surrounding region and to correlate specific geomorphologic features to similar features in the AVIRIS data (Fig. 3). Analysis of the AVIRIS hyperspectral image cube to identify spectral endmembers and to classify the scene revealed the presence of units dominated by dolomite and kaolinite, among others. The area of the landing site is clearly identified as occurring in a unit dominated by dolomite (Figs. 3, 4). Although a Mössbauer spectrometer was not used in this test, the AVIRIS data, which extend to <0.5 μm, indicate two spectrally distinct associations of kaolinite with goethite (Fe-oxyhydroxide, as suspected from CMI examination of rocks at the landing site, along with hematite) and with jarosite (Fe-bearing sulfate). The dolomite-rich unit is shown in the AVIRIS scene to be related to a major mountain-forming sedimentary rock unit north of the basalt flow that caps the older sediments and felsic volcanic strata inferred at the landing site.



Acknowledgements: The Field tests were supported by NASA grant NAG5-7830.

References: [1] Arvidson, Baumgartner, Schenker, and Squyres, FIDO Field Trials In Preparation For Mars Rover Exploration And Discovery And Sample Return Missions, this Volume.

Fig. 3. Classification map derived from AVIRIS data showing aerial photo, visible-light and mineral map insets for the landing site.

EXPLORING MARS WITH BALLOONS AND INFLATABLE ROVERS. Jack A. Jones, James A. Cutts, Viktor V. Kerzhanovich, Andre Yavrouian, Jeffery L. Hall: Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena CA 91109; Steven Raque and Debbie A. Fairbrother: Goddard Space Flight Center, Greenbelt MD 20771. E-mail: Jack.A.Jones@jpl.nasa.gov, James.A.Cutts@jpl.nasa.gov, Viktor.V.Kerzhanovich@jpl.nasa.gov, Andre.Yavrouian@jpl.nasa.gov, Jeffery.L.Hall@jpl.nasa.gov, Steven.M.Raque.1@gsfc.nasa.gov, dafairbr@pop800.gsfc.gov

Introduction: Until now, the exploration of Mars has taken place with global coverage of the planet by satellites in orbit or with landers providing very detailed coverage of extremely limited local areas. New developments in inflatable technology, however, now offer the possibility of in situ surface and atmospheric global studies of Mars using very lightweight rovers and balloons that can travel hundreds or even thousands of kilometers relatively quickly and safely. Both systems are currently being tested at JPL; preliminary results show great promise. One of the balloon technologies offers the additional bonus of being able to land payloads on Mars much more gently than parachutes, yet with considerably less mass.

Inflatable Rovers: The inflatable rover being developed at JPL uses novel, large, inflatable wheels to climb over rocks, instead of traveling around them. This enables the rover to traverse over the vast majority of the Martian surface. Preliminary tests using commercial nylon balloons as tires, a rigid metal chassis, and a simple joystick control have shown great promise [1]. Tests have been successfully conducted in rugged rocky canyons, on giant sand dunes, and on calm lakes, simulating the liquid methane lakes anticipated on Saturn's moon Titan (see Figure 1).

The first full-size bench model of the Inflatable Rover (Figure 1) has two 1.5-meter diameter rear-drive wheels with a forward steering wheel of the same size. The 20-kg prototype rover has two Micro Mo coreless motors with planetary-reduction gears. The two motors propel the rover at 2.0 km/hr, using only 18 W of power on level terrain. Considering Mars' reduced gravity of 0.38 kg, this same 18 W of power could propel the vehicle at approximately 5 km/hr in level terrain.

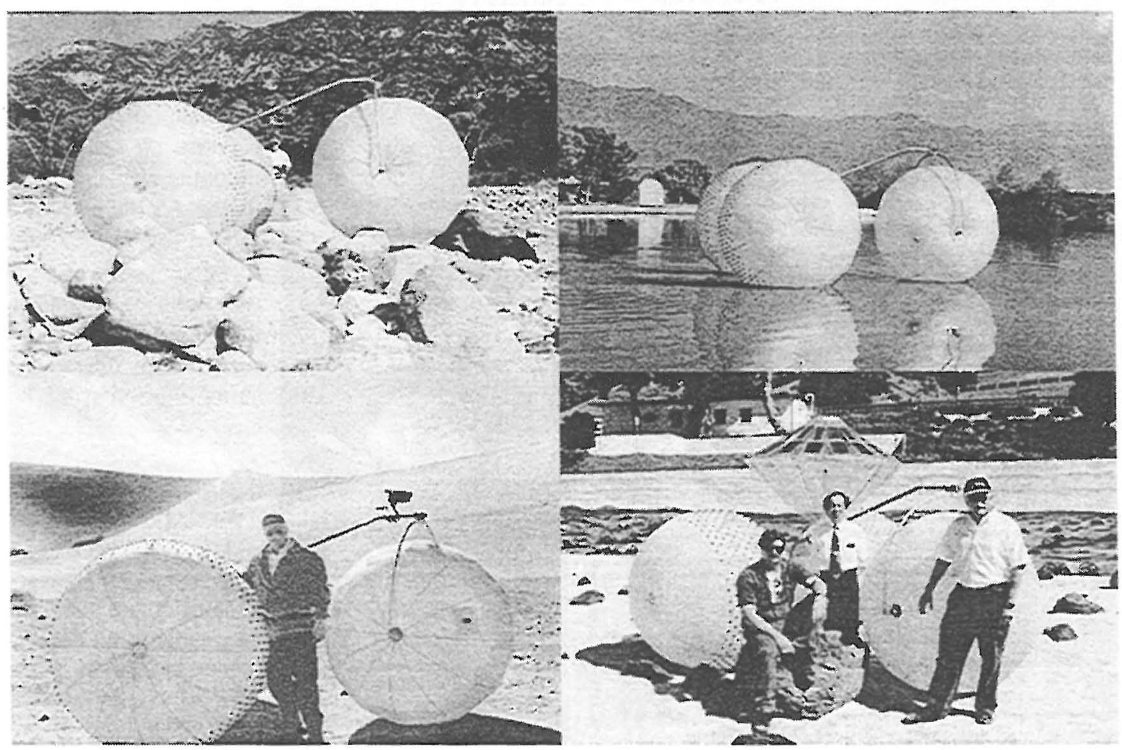


Figure 1: The Inflatable Rover Drives on all Terrains

Balloons: Different well-known types of balloons provide flight duration from about ten hours to several weeks and eventually months. Solar-heated hot air balloons can fly for about ten hours of daylight, although much longer at the martian poles during summer. Conventional zero-pressure ballooons can fly 1.5-2 days with ballasting, overpressure balloons with a guiderope (the Russian-French Mars Aerostat project) can fly up to 7 days, and constant volume superpressure balloons can fly up to several months at a nearly constant altitude. With average martian winds of ~15 m/sec, the flight path of aerobots would vary from 500 km for solar-heated balloons to tens of thousands of kilometers for super-pressure balloons. Balloon altitude control systems are currently under development for Mars, as well as for Venus, Titan, and the giant gas planets [2]

Solar Montgolfieres: A lightweight, solar heated, hot air balloon, known as a Montgofiere, has been in test at JPL for more than two years. This balloon shows great promise for exploring vast areas of the Martian atmosphere (see Figure 2), as well as for soft landing payloads on Mars much more gently and for less mass than parachutes. Montgofieres are named after the 18th-century French brothers Joseph-Michel and Jacques-Etienne Mongolfiere who first flew hot air balloons. Recent tests have already confirmed the ease of altitude deployment and filling of these solar hot air balloons. Furthermore, JPL has recently demonstrated actual landings and re-ascents of solar hot air balloons using a novel, lightweight top air vent [2].

The Montgolfieres are deployed with relative ease by dropping a packed balloon that has a hole in the bottom with a payload (gondola) hanging beneath the balloon. The payload pulls the Montgolfiere down, with the hole acting as a ramjet to fill the balloon, typically in 1 to 2 minutes; solar heat then provides buoyancy in approximately one additional minute. A number of high-altitude (32 km to 34 km) deployment tests have already taken place at JPL.

The development of an ultra-lightweight composite film—weighing only 7 gm/m^2—allows for very lightweight Montgolfieres to fly at Mars. The film consists of 14-gauge (3.5 micron) mylar film with rimstop scrim material bonded to it. A 4-kg, 13 meter diameter Montgolfiere with a metallic film coating can fly at 4-km altitude while carrying a 1-kg imaging and science gondola. This same Montgolfiere can be used to soft land Mars payloads varying from 5 kg (1m/sec impact velocity) to 40 kg (15 m/sec impact velocity). After landing the payload, the Montgolfiere can ascend for a full day of imaging and science while traveling many hundreds of kms. If landing in a summer polar region, the same Montgolfiere could travel many thousands of kms over a period of many days. It should be noted that small leaks do not effect a Montgolfiere's endurance because leaking air is quickly replaced.

Helium Aerobots: Helium superpressure balloons are balloons that have an internal pressure somewhat higher than ambient pressure. With a constant volume, they fly at a nearly constant altitude wherein the mass of atmosphere displaced is equal to the total mass of the balloon, payload and contained helium [3]. Although the anticipated flight duration is much longer than that for Solar Montgolfieres, the helium superpressure balloons are somewhat heavier and involve more risk, since one must bring along a pressurized supply of helium (as opposed to filling with ambient air) and one must be assured of a fully impermeable balloon membrane.

Extensive work is presently underway at NASA to help confirm the use of helium superpressure balloons for long-term missions at Mars. A comprehensive test program (MABVAP – Mars Balloon Validation Program) designed to address the most important issues was initiated in JPL in late 1997. The program includes development and tests of materials, balloon and inflation system prototypes, packaging and deployment methods, laboratory, vacuum chamber tests and flight tests at low altitude and in the stratosphere. Four NASA Centers (JPL, Langley, Dryden, and Glenn) as well as several industrial partners are involved in this program. Development of new modeling and simulation tools by JPL and GSFC/Wallops Flight Center is part of the program.

References: [1] Jack A. Jones et al. (2000) *Space 2000 Robotics Conference*, February 2000. [2] Jack A. Jones, (2000) *IEEE Aerospace Conference,* March 2000. [3] James Cutts and Viktor Kerzhanovich, The Planetary Report, 1999.

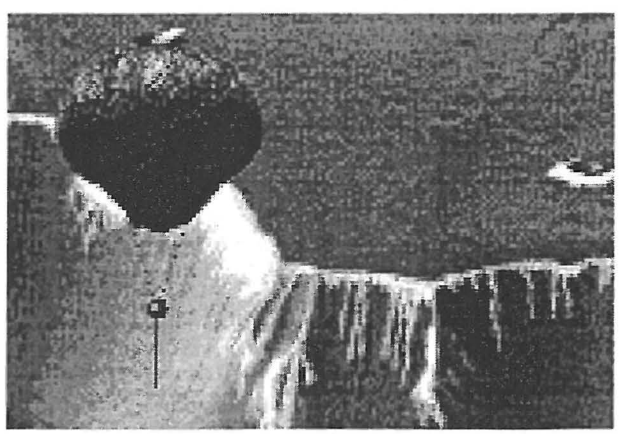


Figure 2: Montgolfiere in Flight

MARS SAMPLE RETURN WITHOUT LANDING ON THE SURFACE. A. J. G. Jurewicz, Steven M. Jones, and A. S. Yen,[1] [1]NASA-Jet Propulsion Laboratory/California Institute of Technology (M/S 183-501, 4800 Oak Grove Dr., Pasadena Ca 91109; JUREWICZ@GPS.CALTECH.EDU).

Introduction: Many in the science community want a Mars sample return in the near future, with the expectation that it will provide in-depth information, significantly beyond what we know from remote sensing, limited in-situ measurements, and work with Martian meteorites. Certainly, return of samples from the Moon resulted in major advances in our understanding of both the geologic history of our planetary satellite, and its relationship to Earth. Similar scientific insights would be expected from analyses of samples returned from Mars. Unfortunately, Mars-lander sample-return missions have been delayed, for the reason that NASA needs more time to review the complexities and risks associated with that type of mission. A traditional sample return entails a complex transfer-chain, including landing, collection, launch, rendezvous, and the return to Earth, as well as an evaluation of potential biological hazards involved with bringing pristine Martian organics to Earth.

There are, however, means of returning scientifically-rich samples from Mars without landing on the surface. This paper discusses an approach for returning intact samples of surface dust, based on known instrument technology, without using an actual Martian lander.

Concept: Recent images of Mars have shown that dust devils are a common occurrence [1]. In addition, local and global dust storms can also introduce micron-sized particles to the upper atmosphere. Estimates of settling times suggest that small particles can remain suspended for months to years [2]. These calculations are compatible with observations of a haze layer located at 20-35 km in altitude [3]. While water and CO_2 ice may be chiefly responsible for the observed haze, its presence is consistent with suspended dust acting as condensation nuclei. An altitude of 35 km is comparable to the aerocapture altitude (40 km) originally planned for the Mars sample return orbiter. Thus, it may be possible to collect high-altitude dust samples from an orbital vehicle for return to earth. Collection of suspended particles could provide a sampling of the fine particles in the global soil unit and, accordingly, valuable insight into geologic processes on Mars.

Prior Art: Previously, many techniques have been used to collect small particles for scientific analyses. The scenario proposed later in this paper is based in great measure on the following two methods:

1. Earth-based. High-altitude, supersonic planes such as the SR-71 Blackbird are routinely equipped with a silicon-oil containment vessel for catching dust at high speeds in the upper atmosphere. Because we are usually not interested in the composition of Earth dust, we sort through the collected material, looking for micrometeorites and interstellar dust particles.

2. Deep space. The *Stardust* and *Genesis* missions will sample cometary dust and the solar wind, respectively, by exposing collector arrays to particle streams. Hypervelocity impacts implant material in collectors which are effectively stationary relative to the particles. The collectors are subsequently returned to earth for laboratory analysis or the captured material.

Clearly, both of these exact approaches are impractical on Mars. We are not going to send up an SR-71, nor are the Martian dust particles going to hit passive collectors at hypervelocities. However, sending a high-altitude, supersonic craft into the Martian upper atmosphere to collect suspended particles may be possible.

Candidate scenario: Consider an orbiting satellite monitoring the vertical profile of dust in the Martian atmosphere. During a period of intense dust activity it could execute a deorbit burn, thus dropping the periapsis to an altitude compatible with collecting dust samples. Collection of the particles would involve an approach similar to that employed on the *Stardust* spacecraft: Aerogel would be used to capture the dust. The collectors would then be retracted into the spacecraft and returned to earth for extraction and analysis of the samples.

There is obviously a tradeoff between achieving a sufficiently low altitude to collect many dust particles and not overheating the spacecraft or ablating the exposed collector. However, the trajectory, the speed of the pass, the duration of the collection period, and the composition and physical characteristics of the aerogel itself can all be optimized.

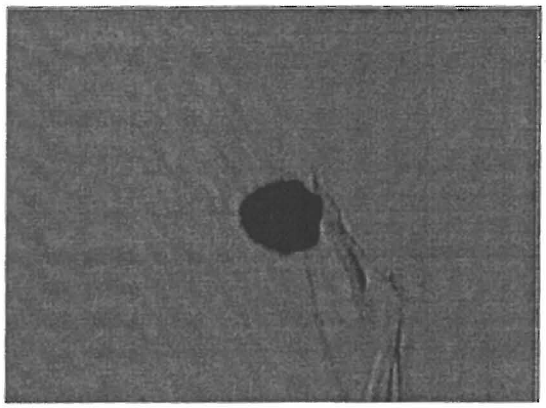
Aerogel: Aerogel has the unique property of stopping particles impacting at hypervelocities while keeping the bulk of the impactor intact. It is also lightweight, tough, and resistant to high temperatures.

To date, all of the experiments which use aerogel as particle collectors employ silica aerogel. Silica aerogel is optically clear-to-translucent, which makes it easy to identify and locate particles after they have been captured. Earlier workers worried about the purity of the aerogel degrading scientific analyses of carbon-bearing IDP's [4]. However, since aerogel is made from liquids, these can be purified/distilled at the start of the process, and residual organics removed by a bake-out

MARS SAMPLE RETURN WITHOUT LANDING ON THE SURFACE. A. J. G. Jurewicz et. al.

step at the end of the process. Indeed, ICP-MS analysis on *Stardust* aerogel showed inorganic impurities at the ppm range and modest heating resulted in carbon content of ~ 0.5% (wt%).

A short history of aerogel capture as part of the evaluation and analysis of particles from an intact-capture experiment placed on the MIR space station, which, is given in [5].



A photomicrograph of a particle captured in aerogel. This particle was implanted by hypervelocity impact testing for the *Stardust* mission. The aerogel itself is a low-density layered silica-aerogel which was being tested as a capture medium for interstellar particles. This particular particle (black) is diamond, approximately 30 microns in diameter. The associated, irregular lines around it (running sub-vertically through the picture) are the track the particle made in the aerogel.

Although silicon aerogel is excellent for intact capture of particles, we believe that there may be better materials available. The primary problem with silicon aerogel is that many of the particles that we would capture while collecting Martian dust would also be silicates. The surfaces of the silicate particles would interact with the silica aerogel during capture because, during the capture, the kinetic energy of the particle is converted in part to heat. While this is good in that it mitigates any Martian biohazard, it also means that the outermost portion of the captured particles is generally ablated. The silica aerogel would make it much more difficult to reconstruct the outer, ablated portion of the captured particle.

Aerogel does not have to be made from silica, however. Aluminum, zirconium, titanium, tin and a variety of other oxide aerogels have been produced. In non-silicate aerogel, it may be more difficult to locate the captured particles, because the aerogel tend be translucent or opaque. Still, technology that would be useful for locating these particles through other than visual means (e.g., x-ray imaging; [6],[7]) does exist.

Once the particle is located, it would be less of a problem separating the chemistry of the original silicate particle from the surrounding aerogel. This better understanding of the chemistry of the captured particle would clearly increase the science return.

Tin-oxide aerogel is potentially an outstanding candidate non-silicate aerogel in that it is transparent [8, 9], allowing for optical location and retrieval. Perhaps more important, tin oxides have also been shown to exhibit selective adsorption of certain gases such as CO, CO_2, CH_4, C_2H_5OH, NO_2, NO_X, etc. [10]. Thus, if these gases were released during the capture of a hydrated or non-silicate particle, they would tend to be adsorbed by the oxide network and thus captured along with the non-volatile material.

Summary: Given our current technology, sending in a high-altitude, supersonic craft for intact capture of suspended particles using aerogel may be a real possibility. The spacecraft trajectory, the speed of the pass, the duration of the collection period, and the composition and physical characteristics of the aerogel itself can all be optimized for the mission. For example, we note that, for the *Stardust* mission, gradient density aerogel was developed. Subsequently aerogel with other gradient properties, i.e., dopant, oxide, etc., have been produced [11]. So, by being able to control the properties of the aerogel, collectors can be tailored to optimize the capture the type of dust present.

References: [1] Edgett, K. S. and M. C. Malin (2000) LPSC XXXI, #1067. [2] Murphy et al. (1990) J. Geophys. Res., 95, 14629-14648. [3] Titov, D. V. et al. (1997), Planet. Space Sci., 45, 637-651. [4] Huang H. -P. et al. (1994) *Planet. Space Sci., 42 (11)* 947-954. [5] Horz F. et al. (1999) *NASA/TM –1999-209372*. [6] Jurewicz A. J. G., et al (2000) LPSC XXXI, #1836. [7] Flynn G. J., et al (2000) LPSC XXXI, #1772. [8] Wu, N.-L. et al (1996) J. Mat. Res., 11(4) 813 - 820. [9] Wang, S.-Y. and N.-L. Wu (1998) J. Non-Cryst. Solids 224, 259 - 266. [10] Gopel W. and K. D. Schierbaum (1995) SnO2 sensors: current status and future prospects, Sensors and Actuators B, 26-27, 1-12. [11] Jones, S. M. (2000) Proc. Soc.Photo-Opt. Instr. Eng., 3943 (V) 260-269.

Acknowledgements: Great thanks to Harold Connolly for his editorial comments, and to Don Burnett for his guidance and support.

IN-SITU RESOURCE UTILIZATION: LAYING THE FOUNDATION FOR "LIVING OFF THE LAND"

D. I. Kaplan, NASA Johnson Space Center, Code EX13, 2101 NASA Road 1, Houston, Texas 77058, david.kaplan@jsc.nasa.gov

1. ISRU IS A HIGH-PRIORITY HEDS REQUIREMENT

The technology to manufacture rocket propellants, breathing and life-support gases, fuel cell reagents, and other consumables on Mars *using indigenous Martian resources* as feedstock in the production process is known as IN-SITU RESOURCE UTILIZATION (ISRU). Several studies of the long-term, committed exploration of Mars [1] by humans show that ISRU is essential . . . an enabling technology. The recognized value of ISRU to human exploration is reflected in the **NASA Strategic Plan**. In the description of the "Strategies and Outcomes" of the Human Exploration and Development of Space (HEDS) Enterprise, the **NASA Strategic Plan** states[1]:

> The [HEDS] Enterprise relies on the robotic missions of the Space Science Enterprise to provide extensive knowledge of the geology, environment, and resources of planetary bodies. The Space Science Enterprise missions will also demonstrate the feasibility of utilizing local resources to "live off the land."

2. ISRU IS MISSION ENHANCING FOR ROBOTIC EXPLORATION OF MARS

The incorporation of ISRU technology into robotic sample return and robotic outpost missions will enable larger samples to be returned and increased surface mobility and science to be performed. (For example, a JPL Team-X study completed in November 1999 compared performances of a solar powered rover versus a fuel cell (high-pressure oxygen and hydrogen reagents) powered rover. The fuel cell provided extended roving capabilities and power on demand for science instruments. The production rate to replenish rover fuel cell reagents is approximately equivalent to that needed for a Mars Sample Return mission.)

Additionally, utilizing ISRU on sample return and outpost missions will provide important flight validation and confidence for its use on human missions. As stated in the **NASA Strategic Plan**, the Space Science Enterprise is committed to developing critical technologies that will enable human exploration[2]:

> The four long-term goals of the Space Science Enterprise are as follows:
>
> . . .
>
> [2] Pursue space science programs that enable and are enabled by future human exploration beyond low-Earth orbit—a goal exploiting the synergy with the human exploration of space;
>
> [3] Develop and utilize revolutionary technologies for missions impossible in prior decades—a goal recognizing the enabling character of technology; . . .

3. BASIC ISRU RESEARCH HAS BEEN AND IS BEING PERFORMED

The HEDS Enterprise has previously selected two payloads to demonstrate the fundamental processes of ISRU. The Mars In-situ-propellant-production Precursor (MIP) Flight Demonstration Project[3] was initiated in November 1996 and subsequently manifested onboard the Mars Surveyor 2001 Lander. MIP's key objectives are (1) to preferentially adsorb carbon dioxide from the Martian atmosphere and use it in the production of pure, propellant-grade oxygen, and (2) to measure key environmental parameters (including insolance and spectrum of sunlight at the Martian surface, properties of airborne dust, and nighttime deep sky temperatures), which are critical to the design of an end-to-end propellant production plant. The MIP flight hardware is presently being assembled and tested at the Johnson Space Center.

The second payload -- Production of Resources on Mars In Situ for Exploration (PROMISE) – would use the Mars atmosphere and Earth-supplied hydrogen to demonstrate the production of methane (CH_4), carbon monoxide (CO) and oxygen (O_2) for use as propellants as well as to demonstrate the production of oxygen,

---

1 "NASA Strategic Plan," NASA Policy Directive (NPD) 1000.1, 1998, page 27.

2 "NASA Strategic Plan," NASA Policy Directive (NPD) 1000.1, 1998, page 18.

3 The author is the MIP Principal Investigator.

buffer gases (N_2 and Ar), and water (H_2O) for use as life support consumables. Led by the University of Arizona, PROMISE is presently in an extended definition phase that is scheduled to last through June 2001.

	MIP[1]	PROMISE[1]	**Proposed "Relevant-Scale" Flight Demonstration**[2]	Robotic Mars Sample Return mission[2]	Human Ascent from Mars Surface[3]
Production Rate per sol	<1 gm	11 gm	**100 – 300 gm**	800 – 1600 gm	~48,000 gm

1 Power source: solar; 7 hours operation per sol.
2 Power source: solar; 8 hours operation per sol.
3 Power source: nuclear; around-the-clock operations.

4. THE NEXT STEP IS TO DEMONSTRATE ISRU AT A MISSION-RELEVANT SCALE

MIP and PROMISE are relatively small scale experiments designed to demonstrate processes and to operate at production rates of a few grams per sol. Whereas a robotic Sample Return Mission that utilizes ISRU would need to produce propellants at a rate of approximately 800 to 1600 grams per sol.

Ascent of humans from the Martian surface to low Mars orbit will require a propellant production plant operating at a rate of approximately 48,000 grams per sol. Use of ISRU to support Environmental Control and Life Support Systems (ECLSS) and fuel cell power generation would further increase this production rate.

The next necessary step in the advancement of ISRU technology is a flight demonstration of an end-to-end propellant production plant that is sized at a directly-relevant scale to the requirements for a Mars Sample Return mission. The rate of production for this demonstration should be 100 to 300 grams per sol (assuming 7 hours of production each daytime). Power requirements for such operations are estimated to be 100 to 200 watts during daytime. To be relevant, full operations would need to be conducted for 90 days or longer.

Based on the successful operation of such a flight demonstration, it would be a small step to build a system capable of contributing to a Sample Return Mission or to Robotic Outposts.

The strategy for Mars exploration should include such an ISRU flight demonstration – one that is sized at a production rate of 100 to 300 grams per sol – in the 2005 launch opportunity. With data from the operation of this propellant production demonstration, mission managers could confidently rely on ISRU as an integral component of a 2009 Mars Sample Return mission.

5. CONCLUSIONS

ISRU is mission enabling for human exploration of Mars. And ISRU is mission enhancing for future robotic missions, particularly sample return and robotic outposts.

ISRU fundamental processes have been and are being demonstrated.

Flight demonstration of an end-to-end ISRU propellant production plant sized at a mission-relevant scale is the next step for this critical technology.

6. REFERENCES

[1] Hoffman, S. J. and Kaplan, D. I., ***Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team***, NASA Special Publication 6107, July 1997.

MARS COMMUNICATION PROTOCOLS. G. J. Kazz[1] and E. Greenberg[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. Pasadena, CA. 91109, greg.j.kazz@jpl.nasa.gov., [2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. Pasadena, CA. 91109, egreenberg@jpl.nasa.gov.

Introduction: Over the next decade, international plans and commitments are underway to develop an infrastructure at Mars to support future exploration of the red planet. The purpose of this infrastructure is to provide reliable global communication and navigation coverage for on-approach, landed, roving, and in-flight assets at Mars. The claim is that this infrastructure will: 1) eliminate the need of these assets to carry Direct to Earth (DTE) communications equipment, 2) significantly increase data return and connectivity, 3) enable small mission exploration of Mars without DTE equipment, 4) provide precision navigation i.e., 10 to 100m position resolution, 5) supply timing reference accurate to 10ms. [1]. This paper in particular focuses on two CCSDS recommendations for that infrastructure: CCSDS Proximity-1 Space Link Protocol [2] and CCSDS File Delivery Protocol (CFDP)[3]. A key aspect of Mars exploration will be the ability of future missions to interoperate. These protocols establish a framework for interoperability by providing standard communication, navigation, and timing services. In addition, these services include strategies to recover gracefully from communication interruptions and interference while ensuring backward compatibility with previous missions from previous phases of exploration. [4].

Need for Standardization: The diversity of communication links within the future potential Mars environment creates challenging engineering problems. Problems such as frequency coordination, link operations, standard data transfer, product accountability, link performance, scheduling vs demand access of services, and network-wide data prioritization need to be addressed. The CCSDS Proximity-1 Space Link Protocol provides recommendations for dealing with the components of these issues in the physical and data link layers. These include frequency allocation, coding, data rates, link establishment, maintenance, and termination procedures, reliable or expedited data transfer, ranging and time transfer. On top of Proximity-1, the CCSDS File Delivery Protocol at the transport layer provides applications the capability of transporting their data products end to end across the entire space link either expedited or reliably.

Proximity-1 Key Characteristics: Proximity-1 provides standard services for transferring command, telemetry, and radiometric data products across the In-Situ link. It provides a timing service which includes techniques for round trip light time (RTLT) calculation and setting remote spacecraft time. It also provides a messaging service between In-Situ assets. Proximity-1 is a bi-directional protocol using the same format and procedures in the forward (command) as well as the return (telemetry) link. It provides for expedited as well as reliable data transfer. It is truly a modeless protocol meaning all of the services provided do not require that the caller or responder be configured into a particular mode for operations. It supports all types of directionality: full, half duplex, and simplex. It uses a data driven technique as opposed to a managed approach for on-board data processing. It supports both coded and uncoded links as well as asynchronous (variable frame) vs synchronous (fixed frames) links. Communication is point-to-point but includes one to many on the forward link.

CFDP Key Characteristics: CFDP is an international standard for automatic, reliable or expedited bi-directional file transfer between spacecraft or spacecraft and ground, built on top of the CCSDS data link layer. Unlike TCP/IP, it requires no handshaking and is datagram and transaction based to deal with space link characteristics e.g., long RTLT and non-persistent links but is adaptable to fit the proximity link as well. Metadata associated with each transaction describes the data transfer including data processing once the file arrives.

Operational Scenarios: The following scenarios examine operations across two separate links: proximity (landed assets to orbiters) and deep space (orbiters to Earth). The proximity link is characterized by short distance (within 400,000 km), moderate signal strength, and single sessions. The deep space link is characterized by long delays, and weak signals. The following 5 scenarios generically demonstrate operations between Mars landed assets, orbiter relays, and Earth ground stations.

Scenario 1: Simple Relay. The objective is to transfer a file by means of an orbital relay. A file may be transferred from a landed asset to Earth or visa versa. The orbital relay functions as a store and forward node. The on-board command and data handling system manages the data it receives from Earth or the landed asset, as a file in it's on-board file management system. In those cases where the lander does not manage data as a file, the relay orbiter can accept data not organized in files e.g., byte streams, CCSDS packet sets, and create one or multiple files from this data on-board. Once the file is successfully transferred to the orbiter, it takes custody of the data (custody transfer), and relays status back to the lander acknowledging its receipt. Given adequate resource margins on-board the orbiter, the lander can now delete this data providing storage space for future data acquisition.

Scenario 2:Multi-Hop Relay (Rover to lander to orbiter to Earth) Now a rover enters the environment and transfers its data to the lander. The rover having limited computing power and storage does not have the resources to run CFDP. Depending upon the required completeness of the data transfer, the rover utilizes either the expedited or the sequence controlled service of Proximity-1. Both the lander and orbiter function as store and forward nodes. Custody transfer occurs first between the lander and the rover and later between the orbiter and the lander.

Scenario 3:Point-to-Multi-point (forward link) Within the proximity link environment, an orbiter encounters multiple landed assets. Assuming the orbiter has only one transceiver, it can simultaneously communicate to all or a subset of the Mars assets within its field of view. By cycling through a set of spacecraft IDs during the hailing period, the orbiter can a) broadcast commands for all Mars assets, or b) multicast commands to a subset of landed assets e.g., all landers, or c) poll each landed asset to determine the priority of its return link data transfer and once determined choose the asset with the highest priority. The Proximity-1 frame verification rules specify that only data marked with the called asset's spacecraft ID or multicast address will be accepted by the asset.

Scenario 4:Time-Sequenced Point-to-Point (return link) Again assuming the orbiter has only one transceiver, it can time share the return link with multiple Mars assets based upon a priority scheme. It does this by establishing communications with a specific asset by hailing it, limiting the period of the data contact to a subset of the total pass time, terminating the link with that asset before hailing the next asset and repeating the process.

Scenario 5:Point-to-Point Network This scenario will require some form of multiple access scheme. Candidates under study at this time are frequency division multiple access (FDMA), code division multiple access (CDMA), and time division multiple access (TDMA). End-to-End file transfers through a point-to-point network will require the use of CFDP to route the data to the correct end destination.

Transition Plan for Protocol Infusion: The NASA/JPL Mars 2001 orbiter and ESA Mars Express/Beagle II project will be the first Mars missions to implement a subset of Proximity-1 for the In-Situ Martian UHF link. In order for these and future Mars missions to benefit from all the advantages of file transfer, a step wise transition from the current state of on-board protocol development to a complete implementation of Proximity-1 and CFDP is envisioned. A three phased approach below describes how the bi-directional file transfer concept can be infused into future Mars missions. The description below uses a simple communications model of a landed asset, an orbiter relay, and Earth stations as illustrative only.

Phase 1:Expedited CFDP (Deep Space Link)/reliable Proximity-1 Link The objective of this phase is to relay data collected by the landed asset via a reliable Proximity-1 link to an orbiter, store the data on-board, and later transmit that data as a file to Earth using the expedited features of CFDP. This phase does not require the landed asset to transmit nor store its data as a file. This version of CFDP does not include the automated selective repeat (report) feature.

Phase 2: Expedited CFDP (In-Situ and Deep Space)/reliable Proximity-1 Link The objective here is to move the functionality of building the file into the landed asset. The orbiter is provided with the functionality of receiving the file and storing it in the on-board data management. As in phase 1, the orbiter transmits the data as a file to Earth using expedited CFDP.

Phase 3: Reliable CFDP (In-Situ and Deep Space)/ unreliable Proximity-1 Link. Here the landed asset uses the more efficient and reliable QoS (selective repeat methodology) of CFDP to transfer a file to the orbiter using the expedited QoS of the Proximity-1 link. Similarly, for the Deep Space link, CFDP can be run reliably on top of either CCSDS Packet Telemetry [5] or CCSDS Telecommand [6] Standard to/from Earth.

References: [1] Hastrup, R.C. "Mars Network for Enabling Low-Cost Missions," Fourth IAA International Conference on Low-Cost Planetary Missions," IAA-L-0509, Laurel, Maryland, 2-5 May 2000. [2] Consultative Committee on Space Data Systems Proximity-1 Space Link Protocol, CCSDS 211.0-R-2, Red Book Issue 2, Jan. 2000. Available at http://www.ccsds.org/ .[3] Consultative Committee on Space Data Systems File Delivery Protocol, CCSDS 727.0-R-3, Red Book Issue 3, May 1999. Available at http://www.ccsds.org/ [4] Kazz, G.J. "Application of an Extended CCSDS Telecommand Standard for all Mars In-Situ Telecommunication Links," First ESA Workshop on Tracking, Telemetry, and Command Systems, ESTEC, Noordwijk, Netherlands, June 24-26, 1998. [5] Consultative Committee on Space Data Systems Packet Telemetry, CCSDS 102.0-B-4, Blue Book Issue 4, Nov. 1995. Available at http://www.ccsds.org/ . [6] Consultative Committee on Space Data Systems Telecommand Part 2 – Data Routing Service. CCSDS 202.0-B-2, Blue Book Issue 2. Nov. 1992. Available at http://www.ccsds.org/

Utilizing Thermal Infrared Spectra of Mars for Mission Planning. L. E. Kirkland[1], P. B. Forney[2], K. C. Herr[3], E. R. Keim[3]; [1]Lunar and Planetary Institute, Houston, <kirkland@lpi.usra.edu>; [2]Lockheed Martin, <paul.forney@lmco.com>; [3]The Aerospace Corporation, <kenneth.c.herr@aero.org>; <eric.r.keim@aero.org>.

Summary. Reflectance and emission spectroscopy remain the most capable method for mineral identification from orbit. However, to best utilize spectra returned from Mars for mission planning, the current level of understanding of the spectral signature of weathered and rough materials should be considered.

Materials measured in the laboratory tend to have band strengths that are stronger than those measured in the field. This difference results mainly from surface roughness, weathering effects, and the presence of a mixture of different materials in the field of view (mixed pixel effect). Thus it is critical to extend spectral measurements from the laboratory into the field in order to understand the spectral behavior of real-world materials. This is best done by utilizing a combination of airborne, field, and laboratory spectra of terrestrial materials, and then applying the lessons learned to spectra recorded of Mars.

The ability of any spectral instrument to detect and identify minerals depends on a combination of (1) the mineral's band strength and (2) band width; and (3) the instrument's spectral resolution and (4) signal-to-noise ratio (SNR); (5) atmospheric interference. These points are not always considered in quotes of the detection limits for a given instrument and material. Here we discuss these effects, and explain their relevance for assessing the order in which spectral instruments should be flown to best implement a phased approach to "follow the water," and for landing site selection and sample return.

Band depth. The minimum coverage by a material required for detection depends in part on the spectral contrast exhibited by the material. The Thermal Emission Spectrometer (TES) has been returning spectra of Mars covering the wavelength range from ~6 - 50 μm, and these spectra may be used to examine the spectral signature of the surface, and to set detection limits for materials.

For example, in the wavelength range covered by TES, carbonate exhibits clear bands at ~6.5, 11.2, and 35 μm. Figure 1 shows the typical signature in the 11.2 μm region of large particles of carbonate. Strong, clear signatures such as these are expected from massive carbonates, and typical quotes of detection limits are based on these signatures.

However, Figure 2 shows the signature measured in the laboratory and the field of a rough, indurated carbonate (calcrete) [1]. Although this material is also composed of carbonate, surface roughness decreases the spectral contrast as a result of cavity and volume scattering effects [1]. Thus the detection limit for a given material also depends on its physical properties, and not just its composition. When detection limits are quoted, it is important to state the assumed band depths of the material.

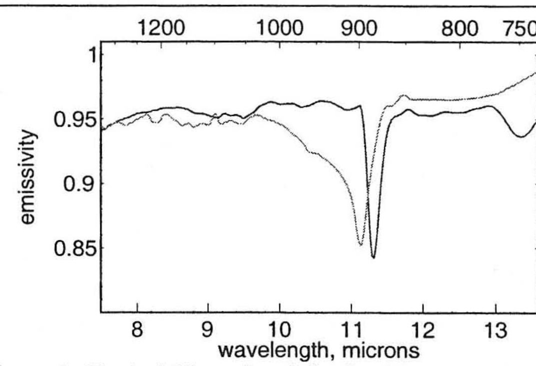


Figure 1: Typical 11 μm band depth. Large particle sizes of carbonates typically exhibit 11.25 μm band depths of ~10%. Shown are spectra of typical carbonates not from Mormon Mesa, measured by J. Salisbury in hemispherical reflectance of 500-1500 μm particle sizes, to examine the expected signature from typical massive carbonates. This was the band depth expected of the massive calcrete [1].

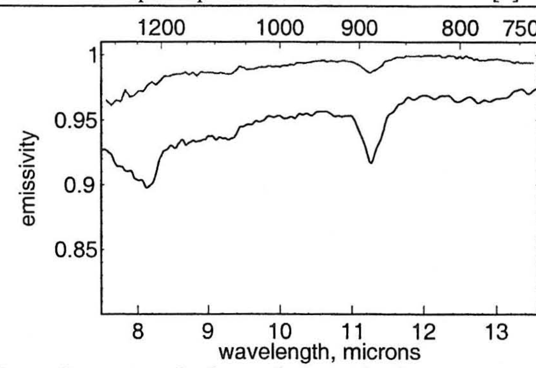


Figure 2: spectra of calcrete (indurated calcite) measured by the airborne hyperspectral imager SEBASS (red) and in the lab (black). The SEBASS field of view was filled by 100% calcrete. The SEBASS spectrum has had an atmospheric correction applied. The lab spectrum was measured in hemispherical reflectance by Paul Adams (The Aerospace Corp.), converted using emissivity=1-reflectance (Kirchoff's Law). Surface roughness causes the difference in 11.25 μm band strength between the field (SEBASS) and lab spectrum. (sample mm4bhr)

Spectral resolution and SNR. The ability of an instrument to detect and identify a material also depends on its spectral resolution and SNR. Poorer spectral resolution causes the recorded spectral features to have lower contrast. Note for example the difference in the TES and simulated Surveyor 2001 THEMIS signatures in Figure 3.

In addition, low spectral resolution decreases information content, which decreases the ability to identify a material, even when it can be detected. It should be noted that there is a difference between detection, discrimination, and identification, and the abilities of each current and planned instrument should be considered. *Detection* requires a signal that rises to a statistically meaningful level above the noise level; *discrimination* requires the signal be detectable and also different from the surrounding materials; and *identification* requires both discrimination and a spectral shape that can be considered unambiguous.

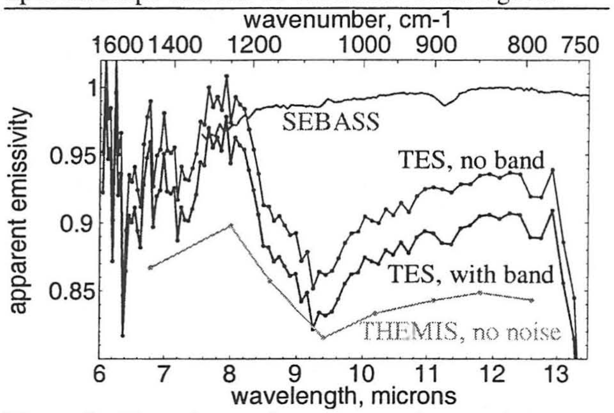


Figure 3: The red trace shows a remotely sensed signature (SEBASS) of a rough, indurated carbonate (calcrete; note the 11 μm band); TES spectra with and without the 11 μm band imposed; and THEMIS (green trace) simulated from TES, but no noise. The SEBASS spectrum recorded a region where calcrete filled the field of view (Figure 4). This illustrates the effects of noise, and the reduced spectral detail exhibited by a 9-band radiometer (THEMIS). Both reduce the ability to detect and identify materials.

Relevance to planning. Here we use results of a spectral study of "White Rock" as an example of the relevance of these effects for mission planning. "White Rock" is a relatively bright deposit within a crater near 8S/335W [2] (Figure 5), and it has been suggested that it may be a deposit of an interesting material such as carbonate or sulfate [3]. If true, this would make it an interesting exobiology landing site [4].

However, Ruff *et al.* [5] conclude that TES spectra recorded of White Rock exhibit the spectral behavior of a blackbody (emissivity = 1) over the spectral range that TES measures, and over which they have obtained an acceptable atmospheric correction, 7.7 to 12.5 and 20 to 40 μm (1300 to 800, and 500 to 250 cm^{-1}) [5].

This blackbody signature is consistent with (1) finely particulate material, such as aeolian dust [5]; or (2) vesicular or rough surfaces, such as the rough carbonate at Mormon Mesa. Differentiating between the two possibilities, and determining the composition of White Rock will require higher SNR measurements, or the measurement of many additional spectra for extensive averaging.

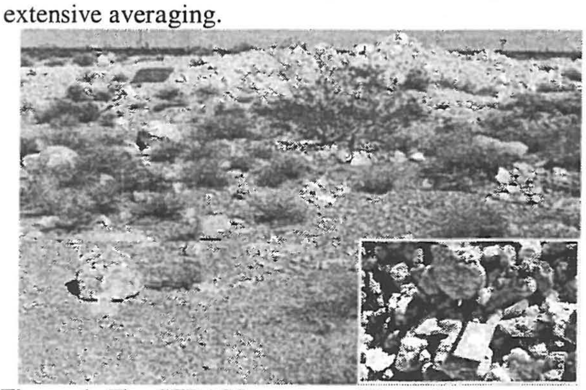


Figure 4: The SEBASS spectrum (Figure 3) measured the calcrete shown above, where calcrete filled the field of view. A diffuse target (1 m^2) is in the upper left. The inset shows a close-up of the spoil top.

It is important to consider this result when examining when and how to incorporate these data sets into planning for landing site selection and sample return, and when examining what critical gaps may remain in our ability to select the most desirable land sites. One critical gap that remains is the measurement of very high information content spectra of targeted regions, which would provide the best support for landing site selection.

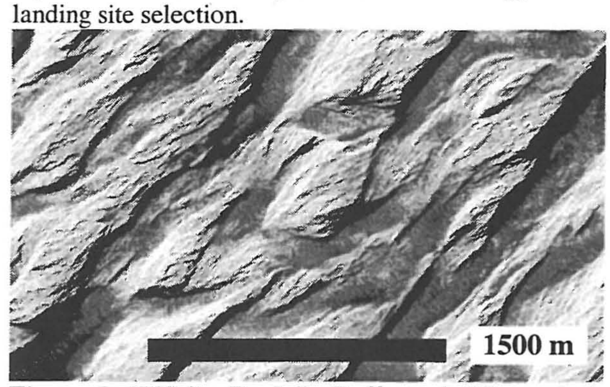


Figure 5: "White Rock." Ruff *et al.* [5] conclude that TES spectra of White Rock exhibit the signature of a blackbody (emissivity = 1). This is consistent either with a material that has no spectral features across these regions [5], or a material that is rough and pitted, such as the indurated carbonates at Mormon Mesa [1]. This second possibility should be taken into account in mission planning based on these data sets. [Image subset of MOC image FHA-00875, centered near 335.3W, 8.2S; 3 m per pixel.]

References. [1] Kirkland L. et al. (2000) *LPSC abs.1876 and LPSC abs.1915*; and this workshop. [2] McCauley J. (1974) *NASA SP-329*, 170. [3] Ward A. W. (1979) *JGR 84*, 8147. [4] Ruff S. et al. (2000) *LPSC abs.1945*. [5] Farmer J. D. and Des Marais D. J., (1999) *JGR 104*, 26,977.

A Field Study of Thermal Infrared Spectral Signatures, with Implications for Studies of Mars. L. E. Kirkland[1], K. C. Herr[2], E. R. Keim[2], P. B. Forney[3], J. W. Salisbury[4], J. A. Hackwell[2]; [1]Lunar and Planetary Institute, Houston, <kirkland@lpi.usra.edu>, [2]The Aerospace Corporation, <kenneth.c.herr@aero.org>; <eric.r.keim@aero.org>; <john.a.hackwell@aero.org; Lockheed Martin Missiles and Space, <paul.forney@lmco.com>; [4]Johns Hopkins University, <salisburys@worldnet.att.net>.

Summary. Data recorded of indurated, weathered carbonates by the airborne hyperspectral imaging spectrometer SEBASS show that some massive carbonates exhibit dramatically reduced spectral contrast for the strong carbonate bands at 6.5 and 11.25 μm. If massive carbonates are present on Mars, this type of reduced spectral contrast could explain why they have not been detected using thermal infrared data sets, including the Global Surveyor Thermal Emission Spectrometer (TES). It could also cause similarly rough carbonates to be missed by the planned 2001 nine-band radiometer THEMIS. On the other hand, SEBASS data demonstrate that these deposits can be detected by spectra recorded with sufficient signal-to-noise ratio (SNR).

The observed reduction in band contrast is significant, and we conclude it is cause by surface roughness effects [1]. The nature of carbonate and other formations on Mars is uncertain, as well as the amount and kind of subsequent weathering, but a rough surface is certainly a possibility that must be taken into account. These results should be considered in planning for future instruments, and when utilizing thermal infrared spectra for landing site selection.

This effect was found by drawing on expertise and unique technology most commonly used for the Department of Defense (DoD). The significance of the lessons learned illustrate the importance both of extending spectral studies to the field, and of drawing on data sets and expertise from non-traditional groups, in order to best define what is needed to detect and identify interesting materials and desirable landing sites on Mars using infrared spectroscopy.

Background. If Mars had a denser CO_2 atmosphere in its past and surface water, then large deposits of carbonate likely formed [2]. Critical to the validation of this model is the determination of whether carbonates are present. In addition, carbonate deposits would provide important input for landing site selection [3]. Currently, there is no strong spectral evidence for carbonates on Mars, which has long been a puzzle in spectral studies.

Three spacecraft spectrometers have returned thermal infrared spectra from Mars, and these spectral data sets are available to the planetary community. Table 1 gives instrument details.

In the thermal infrared, calcite has clear bands centered near 6.5, 11.2, and 35 μm. However, weathering and surface roughness dramatically reduce the band contrast of most materials.

Field site. Mormon Mesa is near Mesquite, Nevada. It has a cap rock of massive, strongly indurated calcite (calcrete), overlain by loamy soil rich in carbonate and quartz, and significant coverage by fragments of calcrete [4] (Figs. 1 and 2); and localized regions contain limestone in a conglomerate [1,4].

Figure 1: Mormon Mesa. The indurated calcite (calcrete) cap rock is visible along the cliff edge (left), and extensive coverage of calcrete fragments are visible on the mesa top, over a reddish calcite and quartz soil. Shown with The Aerospace Corporation's field spectrometer van, operated by The Surveillance Technologies Department, with two spectrometers to measure the 3-5 and 7-13 μm regions.

Figure 2: Typical calcrete sample, collected with the *in situ* top surface marked for reference, to allow the lab characterization to be performed on the weathered surface that is measured by the field spectrometers and SEBASS.

Data. The Aerospace Corporation's Spatially Enhanced Broadband Array Spectrograph System (SEBASS) recorded unique, high quality spectra of

Mormon Mesa in May, 1999. SEBASS is an airborne, hyperspectral imaging spectrometer (Table 1). High quality field spectra covering the same spectral wavelengths were acquired in December 1999, using two van-mounted spectrometers from The Aerospace Corporation [1]. Additional information is at http://www.lpi.usra.edu/science/kirkland/.

The Aerospace Corporation is a non-profit research arm of the Department of Defense, and specializes in the development and assessment of advanced technology. SEBASS is operated by the Spectral Applications Department, and the field spectrometers by the Surveillance Technologies Department. These collaborators represent groups, expertise, technology, and data sets that are not generally incorporated into planetary studies, but that proved critical to this work.

SEBASS measures with the highest combined spectral resolution and SNR of any terrestrial airborne thermal infrared spectrometer, and so is uniquely capable to detect and examine the signature of spectrally subtle materials. In addition, as a result of the inherent nature of DoD-related studies, members of these groups have decades of experience with applied field spectral studies.

An airborne spectrometer can measure hundreds of thousands of spectra of extended spatial regions, providing the means to study more extended areas and spectral variations than is possible in the laboratory alone. The combined ability of SEBASS to measure relatively large regions, and to detect and identify spectrally subtle materials allowed us to discover that the massive carbonate at Mormon Mesa exhibits an unexpectedly weak spectral signature.

We then investigated in more detail the signature of field type regions found by SEBASS, using a combination of *in situ* field spectrometer measurements and laboratory spectra, and laboratory compositional and textural characterization of field samples [1].

Table 1: Instrument parameters.

instrument	4µm SNR	11µm SNR	4µm $\Delta\lambda$ (cm^{-1})	11µm $\Delta\lambda$ (cm^{-1})
SEBASS		1900	13.7	3.7
M21	n/a	1000	n/a	2
M100		n/a	3.3	n/a
1969 IRS		710	24.7	10
1971 IRIS	n/a	100	n/a	2.4
1996 TES	n/a	345	n/a	20

M21=Brunswick Model 21; M100=Block Engineering Model 100; SEBASS=Spatially Enhanced Broadband Array Spectrograph System; SNR=rms signal to noise ratio, 270K; $\Delta\lambda$=spectral resolution; n/a=not applicable

Observations. SEBASS spectra show that none of the regions covered predominantly by calcrete exhibited a strong 11.25 µm carbonate band. This observation is significant, because it has generally been assumed that a massive carbonate will exhibit a strong 11.25 µm band, and detection limits of carbonates on Mars have been based on this assumption [1]. Our laboratory work indicates that surface roughness causes a cavity effect and volume scattering, which causes the surprisingly weak bands in the calcrete at 6.5, 11.25, and 35 µm (Fig. 3) [1].

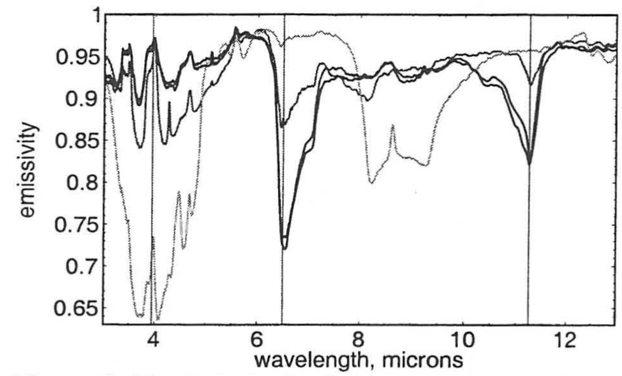


Figure 3: Hemispherical reflectance measurements by P. Adams at The Aerospace Corporation, converted to emissivity using 1-reflectance. Red = typical calcrete from the Mesa top; green = typical soil; blue = black limestone from the arroyo conglomerate; **black = limestone pebble** from asphalt road aggregate. Reference lines at 3.95, 6.5, and 11.25 µm. Note the weakened or absent 6.5 and 11.25 µm troughs in the calcrete and soil, and the clearly evident 3.9 µm peak.

Conclusions. Most spectral studies to determine detection limits have relied predominantly on laboratory measurements of well-crystalline, pure end-members. Desirable instrument parameters and detection limits for remote sensing of Mars are based on those results. However, our results show the importance of extending thermal infrared spectral studies to the field, and the relevance to spectral studies of Mars. The low spectral contrast carbonate deposits at the Mormon Mesa would require a SNR of greater than ~1000 at 11.25 µm to detect, and this exceeds the SNR of any instrument flown to Mars. SEBASS was able to detect the massive calcrete, which validates the use of thermal infrared field spectra to detect these deposits. However the spectra it recorded indicate that if the 1971 IRIS, 1996 TES, or the planned 2001 THEMIS were flown over Mormon Mesa, none would detect the carbonate-rich soil or massive calcrete present.

References. [1] Kirkland L. et al. (2000) *LPSC abs.1876 and LPSC abs.1915.* [2] Pollack J. B. et al. (1987) *Icarus 71*, 203. [3] Farmer J. D. and Des Marais D. J., (1999) *JGR 104*, 26,977. [4] Gardner L. R. (1972) *GSA Bull. 83*, 143.

PRECISION TERMINAL GUIDANCE FOR A MARS LANDER. Dr. William N. Klarquist, SAIC Center for Intelligent Systems, 8100 Shaffer Parkway, Littleton, CO 80127 e-mail: william.n.klarquist@saic.com; Beth E. Wahl, SAIC Center for Intelligent Systems, 8100 Shaffer Parkway, Littleton, CO 80127 e-mail: bwahl@cis.saic.com; James W. Lowrie, SAIC Center for Intelligent Systems, 8100 Shaffer Parkway, Littleton, CO 80127, e-mail: jlowrie@cis.saic.com

Introduction: To date Mars landers have relied solely on Earth-based navigation measurements to achieve a desired landing site. They've had no active guidance and control system to monitor and control the entry and descent trajectory or guide the final landing. This results in very large landing site uncertainties (>180 km x 20 km) and precludes targeting specific, small scale regions such as canyons and flood channels. Moreover, localized hazards cannot be sensed or avoided, resulting in higher mission risk. SAIC's Center for Intelligent Systems, (SAIC-CIS) based on current and past research, believes that reliably accurate landings at pre-selected sites are achievable and that the mission risk associated with local hazards can be greatly reduced. Our concept involves applying an integrated system level solution that leverages the tremendous amount of information available on the Martian environment and applies modern technologies in the areas of visual based navigation, maneuverable parachutes, and advanced sensors.

Technical Approach: The precision landing problem contains four distinct phases, 1) approach, 2) aero-maneuvering, 3) parachute and 4) powered descent. Without precision guidance, an entry and landing system follows an unguided path where large initial navigation uncertainty combined with several forces acting upon the vehicle results in a landing site uncertainty of hundreds of kilometers. A precision guidance system for Mars landers, must employ navigation relative to the landing site and provide closed loop guidance beginning at the approach to the planet, continuing through entry, parachute descent, and propulsive landing. Our research, supports the assertion that a 10 meter landing accuracy is achievable and that local hazards as small as 35 cm in diameter can be reliably avoided. Our concept focuses on the development of a precision guidance system that would provide guidance solutions to the spacecraft control system during the parachute and final powered descent phase.The technologies required to support a precision guidance system are described in Table 1.

Approach and Aero-maneuvering Phases - It has been shown that techniques such as relative navigation to the planet and lift vector control can reduce approach and aeromaneuvering errors. Given these initial improvements, SAIC-CIS is focused on the parachute and powered descent phases where visual based navigation and maneuverability can achieve a precision landing and hazard avoidance capability.

Parachute Phase – Parachute experts have performed initial studies that suggest that a two stage system with a drogue for reducing velocity to M<0.8 and a steerable main parachute provides the best balance of capabilities to support terminal guidance. In particular, a gliding round parachute provides a reasonably large glide path with a quick turn and vertical descent. Opening and closing canopy vents determines the direction of flight in normal descent. The guidance system for the parachute phase would use an imaging sensor (visible or FLIR) to perform landmark recognition to provide high accuracy (4meter) navigation estimates for parachute maneuvering and to establish an initial estimate of terrain roughness. As the parachute descends, stereo image processing uses continuously improving sensor resolution to provide increasingly accurate elevation maps of the terrain. The guidance logic then selects an optimal hazard free landing site close to the selected touchdown point.

Landmark Navigation - Accurate vehicle position refinement with respect to the desired mission path can be achieved by correlating camera imagery obtained during the parachute phase with *a priori* image data acquired from Mars Surveyor using landmark based position estimation. Following a landmark reference, the parachute can begin steering towards the selected landing site. Implementation of a multi-resolution, correlation-based, landmark position estimator will refine vehicle position to within the allowable mission tolerances. In a multi-resolution analysis, low-resolution provides an initial gross position estimate while reducing the search space and conserving processing resources. Following initial correlation, the search space is limited and a higher resolution analysis can be performed. Our initial studies support the feasibility of this approach.

High Altitude Parachute Descent Image Texture Processing - The first opportunity to acquire images of the Martian terrain from either FLIR or visible sensing provides initial cues to the terrain roughness. For FLIR imagery these cues are the temperature differences between surfaces types (rock and soil) and surface orientation with respect to the sun. For visible imagery the high contrast differences between the sunlight and shadow surfaces provides information. For both imaging techniques, the invariant aspect is that uniform image regions represent benign landing sites whereas regions of intensity variation represent changes in surface slope or local rock hazards depending on range. Based on this property an image variance/energy measure will be used as the initial guide for evaluating the acceptability of landing sites in the current field-of-view.

High Altitude Motion Stereo - During the parachute descent phase from 10,000 meters down to 1,200 meters, the trajectory provides an ideal opportunity to build a set of range maps of progressively finer range resolution to guide the vehicle to avoid hazardous regions. Stereo vision uses two or more image frames displaced in space to provide a range map of the surfaces being viewed. The critical requirements for high fidelity range recovery are that the cameras be separated sufficiently to have good range resolution and that there is sufficient contrast detail in the image frames for the matching process to occur uniquely. Over this descent profile the stereo baseline begins at 2000 meters and is reduced over the trajectory to approximately 500 meters at the beginning of the thruster descent. The evolving range map provides a resource for evaluating the surface slope and rock hazards.

Powered Descent Phase - Final maneuvers to a safe landing site are performed during the powered descent phase, which begins after parachute jettison at 1200 m. The guidance system's ability achieve a safe touchdown is driven by the inverse relationship between sensor resolution (improves as a function of time) and lander maneuver envelope (diminishes closer to touchdown). Short timelines and limited maneuverability demand that guidance during this phase transition from motion stereo processing to direct three-dimensional range data. LADAR provides an attractive solution because a verticality transformation provides a direct method of determining hazards. SAIC-CIS has successfully employed LADAR for obstacle avoidance on unmanned ground vehicles and target recognition applications where dynamics and ranges are worse than required for terminal guidance.

The processing capability and high bandwidth required for a Mars lander precision guidance system are addressed in part by utilizing the latest technology in flight processors, partitioning of the sensor processing and guidance solution among multiple processors and application of proprietary image processing algorithms.

Table 1 – Precision Guidance Technology Can Reduce Landing Uncertainty to Less Than 10 Meters

Entry Phase	Existing Approach	Improvements to Achieve Precision Landing
Approach	- DSN Tracking provides nav. estimates. - non-optimal geometry = large uncertainties. - Nav. estimate is handed off to spacecraft prior to entry	- Visual nav. based on centroid or landmark tracking reduces cross track error components. - Trajectory corrections can be made much later with autonomous nav. yielding much higher accuracy
Aero-maneuver	- Ballistic entry with no guidance control	- Controlled lift vector minimizes errors from atmospheric disturbances
Parachute Descent	- Passive descent with no guidance control - No terrain sensing	- High altitude sensing allows early identification of hazardous regions - High altitude landmark recognition reduces position uncertainty in local coordinates by several orders of magnitude - Maneuverable parachute controls descent trajectory; enables precision targeting and hazard avoidance
Powered Descent	- Fixed gravity turn with radar based altitude sensing - Hazards are not sensed or avoided - Error Ellipse at landing can be >180km x 20 km	- Active sensing identifies local hazards to avoid - Target error ellipse < 10 Meters

The Athena Miniature Mössbauer Spectrometer MIMOS II. G. Klingelhöfer[1], B. Bernhardt[1], R. Gellert[1], J. Foh[1], U. Bonnes[2], E. Kankeleit[2], S. Linkin[3], E. Evlanov[3], and the Athena Science Team, [1]Institut f. Anorganische u. Analytische Chemie, Joh. Gutenberg-Universität, Staudinger Weg 9, D-55099 Mainz, Germany (klingel@mail.uni-mainz.de), [2]Institut f. Kernphysik, TU Darmstadt, Germany, [3]Space Research Institute IKI, Moscow, Russia.

Introduction: A first-order requirement of spacecraft missions that land on Mars is instrumentation for in situ mineralogical analysis. Mössbauer Spectroscopy is a powerful tool for quantitative analysis of Fe-bearing materials. The Ahtena Mössbauer spectrometer (MIMOS II) on the martian surface will provide (1) identification of iron-bearing phases (e.g., oxides, silicates, sulfides, sulfates, and carbonates), (2) quantitative measurement of the distribution of iron among its oxidation states (e.g., Fe^{2+}/Fe^{3+} ratio), and (3) quantitative measurement of the distribution of iron among iron-bearing phases (e.g., the relative proportions of iron in olivine, pyroxene, and magnetite in a basalt) in rocks and soils. Mössbauer data will also be highly complementary with chemical analyses from the APXS and the Mini-TES compositional data. Mars is a particularly good place to do Mössbauer mineralogy because its surface is iron rich (~20% Fe as Fe_2O_3 [2,5]). Mössbauer spectrometers that are built with backscatter measurement geometry require no sample preparation, a factor important for in situ planetary measurements.

The Mössbauer Effect

Iron Mössbauer spectroscopy makes use of the resonance absorption of 14.4 kev γ-rays (the Mössbauer effect) by ^{57}Fe nuclei (2.2% natural abundance) in a solid to investigate the splitting of its nuclear energy levels that is produced by interaction with the surrounding electronic environment. ^{57}Co, which decays to the proper excited state of ^{57}Fe, is normally employed as the source of the γ-rays. In general, the nuclear energy level structure of the absorber will be different from that of the ^{57}Co source (because of different oxidation states, chemical environments, and/or magnetic order), which requires modulation of the energy of the source γ-rays to achieve resonance. This is done using the Doppler effect, by mounting the ^{57}Co source on a velocity transducer and moving it with respect to the absorber. A transmission (backscatter) Mössbauer spectrum is the relative number of γ-rays per second passing through (emitted from) an absorbing sample as a function of the relative velocity of the source and sample. Phase and oxidation state identification are determined from peak locations in the Mössbauer spectrum, and peak areas are measures of concentration. If the properties of the absorber vary as a function of temperature, the Mössbauer spectrum will depend on measurement temperature.

The MIMOS II Instrument

The MIMOS II Mössbauer spectrometer system, which is designed and fabricated at the University of Mainz and the TU Darmstadt (e.g.[3]), was originally developed for inclusion on the Russian Mars 98 rover mission. Since then, it has gone through several generations of evolutionary prototypes. A prototype was partially qualified for the Russian-German NANOKHOD microrover (Max-Planck Institute for Cosmochemistry, Mainz, and 'von Hoerner and Sulger GmbH, Schwetzingen; see also this workshop) which was scheduled to fly on the European INTERMARSNET mission. A prototype MIMOS II instrument was successfully tested (data taken under semi-real conditions) on the Rocky-7 Mars prototype rover during the May, 1997, field tests in the Mojave desert [1], and on the FIDO rover during the May 1999 field tests at Silver Lake, California. Engineering and flight-unit MIMOS II instruments have recently been built, qualified and delivered as part of the Athena rover paylaod for the U.S. Mars Surveyor Program.

The MIMOS II system is intrinsically simple, rugged, and has sufficient radiation shielding to protect personnel and other instruments. For Athena, the instrument is split into two parts: the detector head is mounted on a robotic arm and the printed circuit board, which has the circuitry for the instrument control, data acquisition and storage, and communications, is located in the rover's warm electronics box. The main components of the detector head are the ^{57}Co radiation source and shielding, velocity transducer (drive), and silicon PIN diode radiation detectors and their pre- and main-amplifiers. The ^{57}Co source is embedded in a solid rhodium metal matrix which is attached to a titanium holder. The drive has a unique miniature double voice coil electromechanical design.

The total weight of the MIMOS II is about 550 g (410 g for the detector head and 140 g for the printed circuit board, not including the harness). The dimensions of the instrument are about 90mm x 50mm x 40mm for the sensor head, and 160mm x 100mm x 25 mm for the electronics board. The power consumption is 2-2.5 W. The instrument has been fully tested over the expected temperature range (operating: -80°C to +40°C Sensor head; -50°C to +40°C electronics board; non operating: -120°C to +80°C Sensor head; -60°C to +80°C electronics board) and for vibrations over frequency range that was expected for launch and landing of the Mars Surveyor 2001 Lander. The ^{57}Co radioactive Mössbauer source intensity of about 300 mCi at launch will give a 8-12 hr time for acquisition of one spectrum on Mars, depending on total Fe content and which Fe-bearing phases are present. Measurements will be done by placing the detector head against the rock or soil to be analysed. Physical contact is required to minimize possible microphonic noise on the velocity-modulated energy of the emitted γ-rays. The field of view of the instrument is circular (diameter ~1 to 2 cm). The average information depth for Mössbauer data is 100 to 200 μm, assuming basaltic rock composition. The instrument monitors temperature, and adjusts integration periods to assure that the variation in ambient surface temperature during acquisition of a single spectrum is not larger than about ±10 °C, minimizing spectral smearing associated with temperature-dependent Figure 1 shows backscatter Mössbauer spectra obtained with the MIMOS II instrument in the laboratory for five Martian surface analogue samples [4]. Figure 2.a and 2.b show some of the spectra obtained with the flight instrument during the Athena payload integrated systems test in May 2000 at JPL.

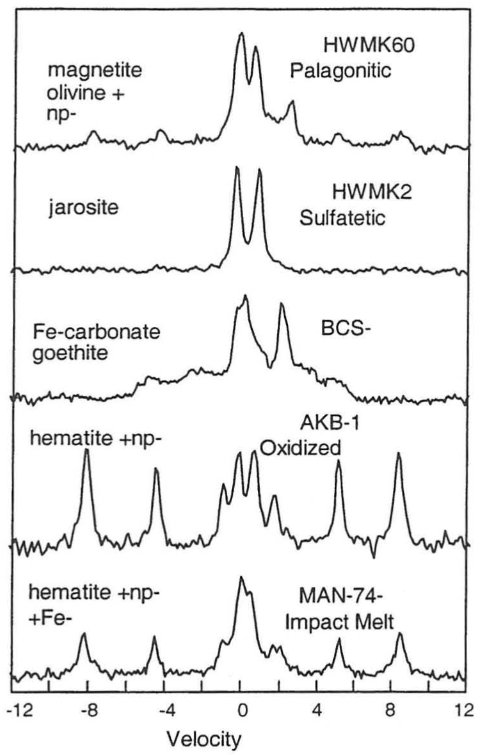


Figure 1. Backscatter Mossbauer spectra (~290 K) obtained with the MIMOS II instrument for Martian surface analogues (after [4]).

References

[1] Arvidson , R.E, et al., *Rocky 7 prototype Mars rover field geology experiments 1. Lavic Lake and Sunshine Volcanic Field, California*, J. Geophys. Res.,*103,* 22671-22688, 1998. [2] Clark, B. C., et al., *Chemical composition of martian fines,* J. Geophys. Res., 87, 10059-10067, 1982. [3] Klingelhoefer, G., et al., *Mineralogical analysis of Martian soil and rock by a mineraturized backscattering Mossbauer spectrometer*, Planet. Space Sci., 44, 1277-1288, 1996. [4] Morris, R. V., et *al Analyses of Martian surface materials during the Mars Surveyor 2001 mission by the Athena instrument payload.* In: Lunar and Planetary Science XXIX, Abstract #1326 (CD-ROM), The Lunar and Planetary Institute, Houston, 1998. [5] Rieder, R. et al., *The chemical composition of Martian soil and rocks returned by the mobile alpha proton X-ray spectrometer: Preliminary results from the X-ray mode,* Science, 278, 1771-1774, 1997.

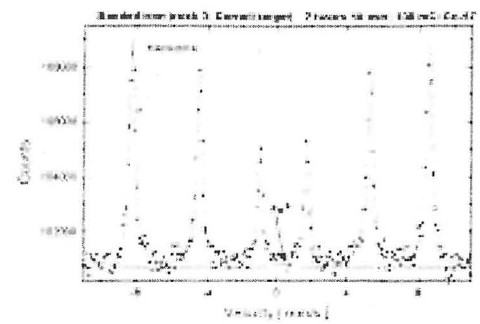


Figure 2.a: Backscatter Mössbauer spectrum (~290K) of a sample of Banded Iron Formation (BIF), obtained with the MIMOS II flight unit during APEX system test May 2000. The spectrum is dominated by the hematite signal (red six line pattern). A minor contribution (close to zero) of a $Fe\text{-}3^+$
doublet component might be present.

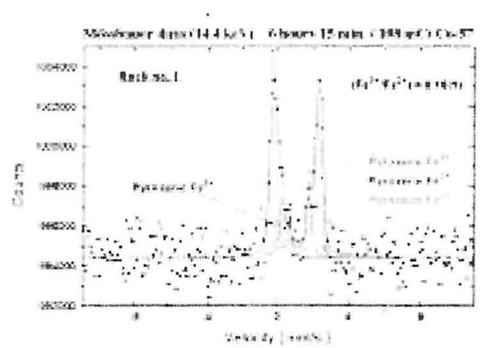


Figure 2.b: Backscatter Mössbauer spectrum (~290K) of a sample of a rock composed of 40% Fe-rich pyroxene, obtained with the MIMOS II flight unit during APEX system test May 2000. The spectrum is dominated by a pyroxene signal ($Fe\text{-}2^+$), with a 10% (in area) contribution of an $Fe\text{-}3^+$ doublet component, also belonging probably to the pyroxene mineral.

A Sample Return Container With Hermetic Seal Kin Yuen Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), Shaheed Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com), Shazad Sadick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sadick@hbrobotics.com), Christopher C. Porter, (Jet Propulsion Laboratory)

Introduction: A sample return container is being developed by Honeybee Robotics to receive samples from a derivative of the Champollion/ST4 Sample Acquisition and Transfer Mechanism[1] or other samplers and then hermetically seal samples for a sample return mission. The container is enclosed in a phase change material (PCM) chamber to prevent phase change during return and re-entry to earth. This container is designed to operate passively with no motors and actuators. Using the sampler's featured drill tip for interfacing, transferring and sealing samples, the container consumes no electrical power and therefore minimizes sample temperature change. The circular container houses a few isolated canisters, which will be sealed individually for samples acquired from different sites or depths. The drill based sampler indexes each canister to the sample transfer position, below the index interface for sample transfer. After sample transfer is completed, the sampler indexes a seal carrier, which lines up seals with the openings of the canisters. The sampler moves to the sealing interface and seals the sample canisters one by one. The sealing interface can be designed to work with C-seals, knife edge seals and cup seals (Figure 1). Again, the sampler provides all sealing actuation. This sample return container and co-engineered sample acquisition system are being developed by Honeybee Robotics in collaboration with the JPL Exploration Technology program.

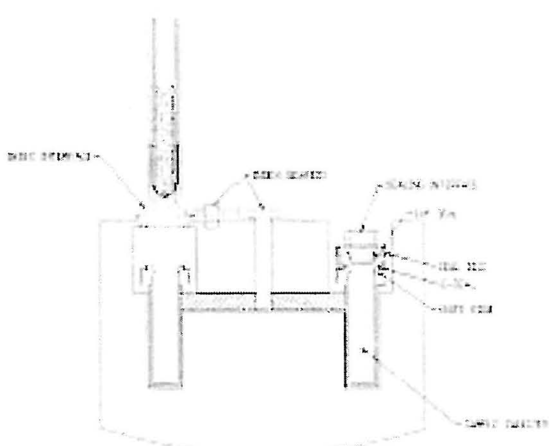


Figure 1: Container Schematic Diagram

Subsurface Coring Sampler: The sample acquisition system designed to work best with the container is a new variation of the Champollion/ST4 Sample Acquisition and Transfer Mechanism (SATM) designed for high volume sampling. The sampler drills to the sampling depth with a plunger-cuter extended. When the desired sampling depth is reached, the plunger-cutter retracts to create a larger sample cavity (up to hundreds of mm in length). The sampler then resumes drilling (coring) until the cavity is filled up or the desired sample length is reached. A shearing (coring) tip is extended to reach the sample stud. Spinning the drill tip again causes the shearing tip to shear the stud to complete the coring operation. The shearing tip also provides the core retention and protection. Since this coring does not require an off center break-off mechanism, a large sample cavity (large diameter core) can be achieved.

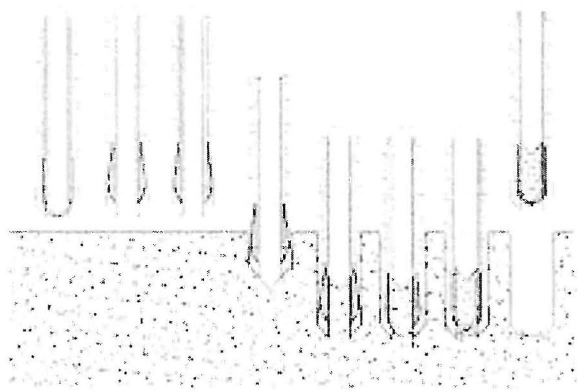


Figure 2. Sample Acquisition Sequences

Sample Transfer and Sealing: After the SATM based sampler with the cored sample returns to surface and engages the index interface of the container, the sampler indexes an empty canister to the sample transfer position (below the index interface). The sampler lowers to the opening of the canister and retracts the shearing element to expose the sampled cavity. The sampler extends the plunger, pushing the sample core into the canister. A clip inside the canister (not shown) captures and retains the core. The sampler retracts back to the index position and indexes the canister from the transfer position limiting contamination. Later on, the sampler interfaces with the sealing interface and indexes a seal to cover the opening of the canister and using the rotation action of the drill tip, drives the seal down to seal the sample. The seal is constrained to a linear motion to prevent any rubbing against the canister to obtain a good clean seal.

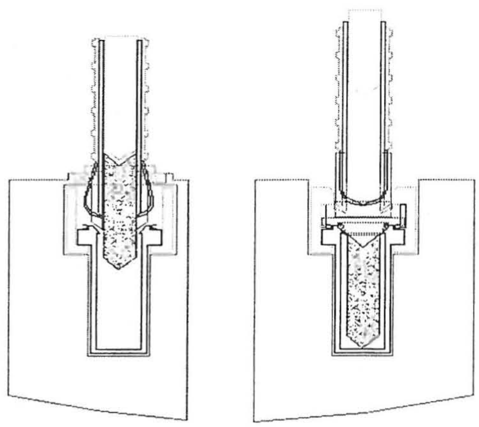


Figure 3 Sample Transfer and Sealing

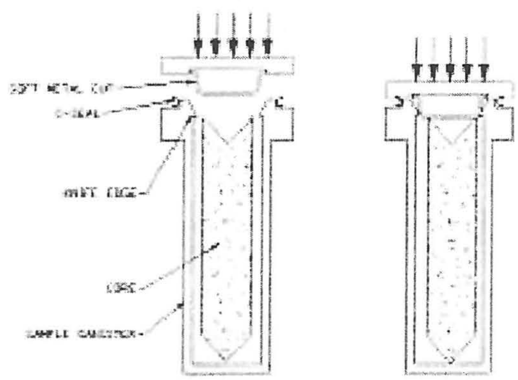


Figure 4 Sealing Schematic

Sample Sealing Development: To date, a few autonomous sealing methods have been developed. Honeybee has tested C-seals (Figure 5) and knife-edge seals. Two new sealing schemes are under development; a soft metal cup seal and a serial-radial seal and will be tested later. The soft metal cup seal is designed for a dusty environment and the built in compliance preserves the sealing integrity under vibration loading and large temperature gradients.

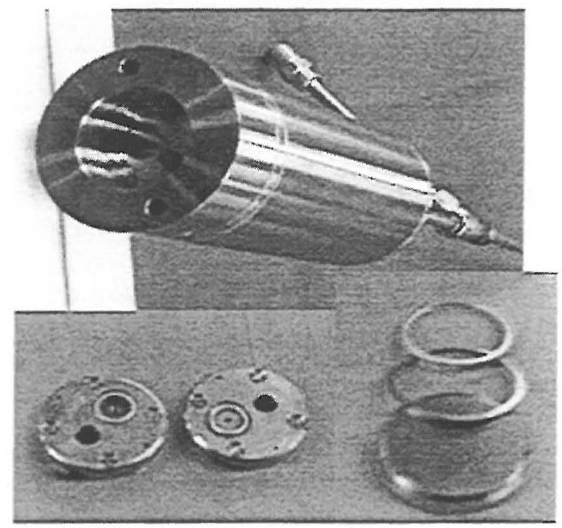


Figure 5 C-seal Test Fixtures

The serial-radial seal uses a series of radial seals to remove leakage and provides multi-fault tolerances. A breadboard of the serial-radial seal is being fabricated (Figure 6).

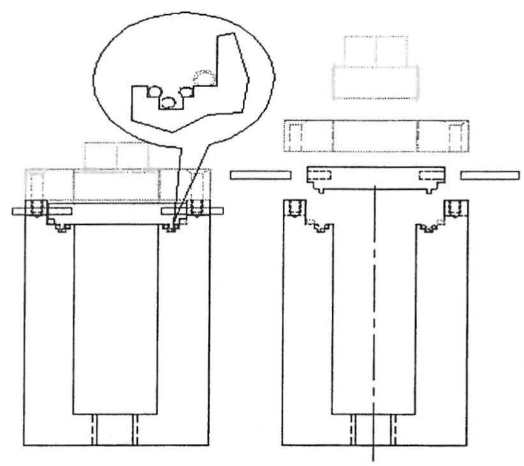


Figure 6: Serial-Radial Seal Breadboard

References: [1]S.Gorevan,S.Rafeek, The Sample Acquisition and Transfer Mechanism (SATM) for The Champollion Cometary Mission, Advanced Devevelopments in Space Robotics AIAA Technology Forum, University of Wisconsin, August, 1996.

IN-SITU PLANETARY CHEMICAL ANALYSIS. S. P. Kounaves[1], M. G. Buehler[2], S. M. Grannan[2], M. H. Hecht[2], and K. R. Kuhlman[2], [1]Tufts University, Department of Chemistry, Medford, MA 02155 (skounave@tufts.edu), [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109.

Introduction: Both, the search for evidence of life on Mars and the assessment of the Martian environment in respect to its compatibility with human explorers, will require the ability to measure and understand the aqueous chemistry of the Martian regolith. Direct in-situ chemical analysis is the only method by which chemical biosignatures can be reliably recognized and the toxicity of the regolith accurately assessed. Qualitative and quantitative determination of the aqueous ionic constituents and their concentrations is critical in developing kinetic and thermodynamic models that can be used to accurately predict the potential of the past or present Martian geochemical environment to have either generated or still sustain life. In-situ chemical characterization could provide evidence as to whether the chemical composition of the regolith or evaporates in suspected ancient water bodies have been biologically influenced [1-3].

Remote/Elemental Analysis: A variety of analytical techniques have been proposed and/or used for determining the chemical composition of Mars and for attempting to detect and identify signatures of past or present life [4,5]. These techniques have included *visual observation* with instruments such as cameras and optical or atomic-force microscopes; *elemental analysis* with such instruments as X-ray fluorescence (XRF) and diffraction (XRD), α-proton backscatter (APX), γ-ray, Mössbauer, Raman, IR, UV/VIS spectroscopies; and *chemical analysis* with gas chromatography (GC), or mass spectrometry (MS). However, none of these techniques provided (or where even capable of providing) any direct information about the chemical speciation or reactivity of the Martian regolith under previous or current aqueous conditions.

Direct observation of an identifiable life form or fossil by optical instruments in a single sample is highly unlikely. Remote sensing instruments have provided a wealth if data as to the elemental mineralogy and geological history of the planet [6,7], but are highly inadequate for understanding the chemistry of the planet in terms of indigenous life or interactions with human explorers. Techniques such as XRD, XRF, IMP, and APXS, can provide elemental composition at high limits of detection. In some cases, the data has been extrapolated to provide constraints for the possible origin and evolution of the Martian regolith, and chemical parameters for minerals such as such as oxidation state or elemental composition. However, recent attempts to correlate the IMP spectroscopy and APXS elemental data from the Mars Pathfinder mission have not been productive. Attempts at constraining the dust and soil mineralogy have not yielded physically acceptable results [8]. Even though minerals may reflect the environment in which they are formed [9], the use of remote techniques for determining the suitability of Mars' present or past environment for supporting life will not likely produce data which will be acceptable to the scientific community without direct in-situ chemical analysis.

A direct chemical analysis method such as gas chromatography (GC), but without standards and non-specific detectors, has little chance of identifying a mixture of unknown components. Combining GC with mass spectrometry (MS) can provide identification of compounds, but as with GC the sample must be appropriately prepared for accurate and reliable analysis. Even with such procedures the in-situ inorganic aqueous chemistry of the sample would be impossible to decipher.

More recent technology has allowed the microfabrication of capillary microphoresis devices capable of determining amino acids and their chirality [10]. However, even the data from such devices would not be definitive, since alternate chemical pathways to their generation could conceivably be proposed. *Detection of any single biochemical compound on the surface of Mars (or any planetary body) will never be definitive nor provide sufficient evidence to support a claim of extinct or extant extraterrestrial life.*

No remote elemental analysis can currently provide the levels of detection required to measure chemical substances or properties which would be considered highly toxic to human explorers. Minimum toxic levels of such substances as cadmium, lead, or mercury, or of chemical properties such as pH, oxidizing potential, or chemical reactivity, cannot be determined by any current non-aqueous or remote instrument technique.

Aqueous Chemical Measurements: An environmental analytical chemist on Earth would rarely, if ever, need to know the elemental constituency or mineralogy of a site in evaluating its biotoxicity. The most critical information about biotoxicity lies in the aqueous chemistry. The chemical thermodynamic and kinetic properties of an aqueous system are primary in determining the availability and chemical speciation of most toxic substances. Inorganic substances such as mercury, which may be totally non-toxic in many stable mineralogical forms, may be acutely toxic in ionic form. The same situation will apply to chemical parameters such as pH or redox potential, neither of which is relevant except in an aqueous environment.

Life as we know it, and probably identify it as such, requires an aqueous environment. Deciphering the chemical speciation of this aqueous environment is the key to recognizing therein the biosignatures of any extinct or present life forms. Identifying the soluble (ionic and nonionic) components by reacting a currently dormant environment can provide a "picture" of the thermodynamics and chemical components of a possibly bioactive environment [1,3].

In-Situ Chemical Sensors: Aside from classical wet chemical analysis techniques, the only chemical sensing devices which can provide a wide variety of in-situ ionic chemical information are electrochemical sensors based on the potentiometric *ion selective electrodes* (ISEs) and on dynamic techniques such as *cyclic voltammetry* (CV) and *stripping voltammetry* (SV). Such an array of devices can provide not only the chemical composition of a water-soluble sample, but also several other vital chemical parameters such as pH, conductivity, redox potential, and dissolved gases.

A array of twenty of these sensors, based on the same principle, have already been flight-tested and installed as part of the MECA instrumentation originally slated for the Mars 2001 Lander [11]. The MECA chemical analysis instrument represented a pioneering effort in configuring these types of electrochemically-based sensors for in-situ analysis in a remote hostile extraterrestrial environment. The MECA devices, when hopefully eventually flown, will test this concept and provide data for future versions of such in-situ chemical analysis laboratories.

Further research and development, currently underway and funded by NASA and EPA, is addressing the microfabrication, integration and multiplexing of a larger number of these sensors on a single miniature, low power/mass substrate. The array will consist of specific and semispecific ion selective and amperometric transducers, which can simultaneously and continuously identify and semi-quantitatively determine over 50 organic and inorganic analytes in water-based environments

In addition to the array transduction development, there have also been significant advances, within our labs and elsewhere, in the use of chemometric neural network approaches in analyzing the resulting data from such type of electrochemically-based sensors. Application of multi-sensor arrays is critically dependent on the ability to process and interpret raw sensor data and to model the sample chemistry. The combination of an electrochemical ion sensor array and neural networks can provide rapid and correct *identification and quantification* of multiple ionic species. Multiple sensors for the same ion as well as multiple ions will allow for accurate dynamic recalibration of the individual sensors as well as for quantification of the ionic species present. Self-diagnosis of performance *in-situ* and dynamic recalibration are highly desirable for treatment of changing operating conditions and shifting baselines in the individual ISE sensors. Such a sensor array can posses both the ability to *recognize* the presence of a chemical species and also provide quantitative information.

The development and use of such sensors as part of an in-situ chemical analysis package on a Mars Lander would contribute new science with little development risk, low cost, and would integrate well into several NASA objectives for future planetary exploration. Such a device would provide a chemical "picture" of the Martian regolith and its potential to support life, both Human and Martian.

References: [1] Nealson K.H. (1997) *JGR, 102*, 23,675-86. [2] Shock E.L. (1997) *JGR, 102*, 23,687-94. [3] Gaidos E.J., Nealson K.H. and Kirschvink J.L. (1999) *Science, 284*, 1631-33. [4] Schwartz D.E., Mancinelli R.L. and White M.R. (1994) *Adv. Space Res., 15*, 193-97. [5] Brack A. et al., (1998) *ESTEC*, Noodwijk, Netherlands. [6] Rieder R. et al., (1997) *Science, 278*, 1771-74. [7] Clark B. C. (1993) *Geochim. Cosmochim. Acta, 57*, 4575-81. [8] Bell J.F. et al., (2000) *JGR, 105*, 1721-55. [9] Bishop J. L. et al., (1998) *JGR, 103*, 31,457-76. [10] Hutt L.D. et al., (1999) *Anal. Chem., 71*, 4000-6. [11] Grannan S. M. et al., in Workshop on Mars 2001 (Eds: J. Marshal, C. Weitz), LPI Contribution 991, LPI, Houston, 1999, pp 41-42.

The stakes of the Aerocapture for missions to Mars - Abstract

Th. LAM-TRONG, R.CLEDASSOU, J.M CHARBONNIER

Centre national d'Etudes Spatiales, France

The Hohmann transfer trajectory is an economical way to go from Earth to Mars but a spacecraft has to reduce its speed very significantly upon arrival in order to be inserted into a Mars orbit.

The aerocapture is a way to do that, by using the Martian atmosphere to produce sufficient aerodynamic drag force on a heatshield and achieve the required deceleration.

This presentation will address the major stake of the aerocapture which is twofold :

a) – *Technological*

We will list the different technologies and areas of knowledge related to the aerocapture, identify the risks associated with each of them and finally demonstrate that aerocapture is not as risky as it is said to be.

b) – *Economical*

Aerocapture saves a huge amount of propellant and so allows to improve dramatically the $/kg ratio for any payload at Mars by using this mass saving for payloads and by decreasing the launch cost. This benefit is particularly evident for a return mission because of the amplification factor of the propellant mass for the escape of Mars (« snow ball » effect).

We will have a quantitative analysis of some typical cases of spacecraft vs launcher performance .

We will conclude the aerocapture is interesting for the present robotic missions and certainly a good investment for the future manned missions to Mars.

Concepts and Approaches for Mars Exploration

Part 2

Hosted by

Lunar and Planetary Institute

Sponsored by

NASA Headquarters
Lunar and Planetary Institute

CONCEPTS AND APPROACHES FOR MARS EXPLORATION

Part 2

Hosted by

Lunar and Planetary Institute
July 18–20, 2000
Houston, Texas

Sponsored by

NASA Headquarters
Lunar and Planetary Institute

Convener

Scott Hubbard, NASA Headquarters

LPI Contribution No. 1062

Compiled in 2000 by
LUNAR AND PLANETARY INSTITUTE

The Institute is operated by the Universities Space Research Association under Contract No. NASW-4574 with the National Aeronautics and Space Administration.

Abstracts in this volume may be cited as

Author A. B. (2000) Title of abstract. In *Concepts and Approaches for Mars Exploration,* p. xx. LPI Contribution No. 1062, Lunar and Planetary Institute, Houston.

This report is distributed by

ORDER DEPARTMENT
Lunar and Planetary Institute
3600 Bay Area Boulevard
Houston TX 77058-1113
Phone: 281-486-2172
Fax: 281-486-2186
E-mail: order@lpi.usra.edu

Mail order requestors will be invoiced for the cost of shipping and handling.

Preface

This volume contains abstracts that have been accepted for presentation at the Concepts and Approaches for Mars Exploration workshop, July 18–20, 2000.

Logistical, administrative, and publications support were provided by the Publications and Program Services Department of the Lunar and Planetary Institute.

Contents (Part 2)

MARS EXPLORATION WITH A SELF-REFUELING HOPPER. Geoffrey A. Landis[1] and Diane Linne[2], [1]Ohio Aerospace Institute, NASA John Glenn Research Center mailstop 302-1, 21000 Brookpark Road, Cleveland OH 44135; e-mail geoffrey.landis@grc.nasa.gov, [2] NASA John Glenn Research Center, mailstop 5-10, Cleveland, OH 44135; e-mail Diane.L.Linne@grc.nasa.gov

Introduction: A small reusable "hopper" vehicle, the Mars In-situ Propellants Rocket, is proposed to fly autonomously on Mars, using *in-Situ propellant production* to manufacture rocket propellant directly out of the Martian atmosphere [1]. The MIPR explores the Martian surface under rocket power and can repeatedly takeoff and land, carrying a suite of science instruments over a range of hundreds of meters per hop. The flight demonstration will accomplish a range of technology objectives important to both unmanned probes and to future human missions, including:

demonstration of a sub-orbital Mars launch vehicle

demonstration of a pressure-fed small propulsion system for Mars ascent vehicles

demonstration of a lightweight space engine

and

use for the first time of propellants manufactured in-situ on another planetary body.

In addition to these technology objectives, the MIPR vehicle can carry a science payload that will advance our understanding of the surface and atmosphere of Mars.

Discussion: The Mars Pathfinder mission convincingly demonstrated the value of mobility on a planetary surface, and even though the *Sojourner* rover crawled at less than half a meter per second, and wandered no more than a maximum of twelve meters from the lander, the scientific (and public outreach) value of the *Sojourner* rover was incalculable.

But surface rovers, limited by terrain, cannot explore many interesting territories. If a vehicle were to rise above the surface, it could traverse "impassible" chasms and hop over "uncrossable" cliffs.

A valuable surface explorer would be a rocket-powered hopper able to take off and land repeatedly, carrying a suite of science instruments over hundreds of meters per hop.

The rocket-powered hopper with these key features can achieve such objectives:

- refuels itself autonomously for multiple hops by using solar power to react atmospheric CO_2 into O_2 (oxidizer) and carbon monoxide (CO) (fuel);
- achieves an altitude of several hundreds of meters and traverses a distance of several hundreds of meters during each hop; and
- carries a suite of scientific instruments to a soft landing at the conclusion of each hop.

The hopper will be situated on the science deck of a Surveyor class Mars lander. Once the lander sets down on Mars, the solar arrays will begin to produce power to operate its propellant production plant. The available power will determine the production rate.

The propellant production system is based on the MIP demonstration unit, which is a flight-qualified production plant originally designed to fly on the [now postponed] Mars-2001 Surveyor mission [2]. Our preliminary designs indicate that the production plant will be at least half of the hopper's dry mass. The distance achieved during a hop is a function of launch angle, quantity of propellants, thrust, and dry mass. For initial planning purposes, we have assumed a launch angle of 45° to maximize range. As a technology goal, we want to demonstrate an engine large enough that it can be scaled up for a Mars sample-return mission, where required thrust is expected to be 1700 to 2200 N (400 to 500 lbf). However, it is also important to keep hopper thrust levels low—to minimize mass and to allow a soft landing after each hop. We anticipate engine thrust to be 200 to 700 N (50 to 150 lbf) and are using a thrust level of 350 N (75 lbf) for planning purposes.

Parameters for the candidate vehicle are shown in table 1.

The nature of the hop, therefore, can be described by the dry mass of the vehicle (i.e., the mass to be landed back onto the Martian surface), the O_2 and CO production rates (measured in standard cubic centimeters per minute (sccm)), and the length of time between hops. For example, we have estimated that for 20 kg of dry mass and a production rate of 20 sccm of O_2, the hopper can jump 500 meters every 25 days. For 30 kg of dry mass and a production rate of 40 sccm of O_2, the hopper can jump 1000 meters every 25 days.

Table 1
Mars In-Situ Propellant Ballistic Hopper

Single Hop Range:	0.50 kilometers
Engine Thrust:	335 N (75 lbf)
Engine I_{sp}:	250 sec
Propellants:	O_2/CO (gas)
Total Mass	20.3 kg
Duration Between Hops:	25 days

Sounding Rocket: A proposed alternate vehicle is the Mars sounding rocket. This would be a single-launch vehicle, but it might deploy several payloads to multiple locations. It could be designed for a semi-soft or hard landing but could not be refueled for a second flight. The sounding rocket would obtain the same aerial science data as the hopper (although for only a single flight) and surface information at a single or multiple sites. It could also demonstrate the use of in-situ produced fuel, although for this option the propellant production plant would not be carried onboard. This would greatly reduce its dry mass and thereby allow the single flight to achieve a higher altitude, a longer range, a larger payload, or some combination of all three.

Science: The vehicle serves as a science platform that complements ground and orbital observations. Possible science payloads for the vehicle include:

Aerial photography of landing site. The aerial view of the landing site will be invaluable for placing geological investigations in a proper context. We will get high-detail images at a different sun angle and from a different physical perspective than the images taken by the descent imager during landing. Thus, our aerial images will complement the science data obtained from other means. These images will also provide "aerial reconnaissance" for selecting traverse path and locating interesting targets for rover samples.

Meteorology. Studies of Martian climate and meteorology will benefit greatly from an expanded range of altitudes for temperature and wind measurements.

Vertical profile of aerosols. The aerosols suspended in the Mars atmosphere are a significant climate and meteorology driver; the hopper/sounding rocket scientific payload will measure the vertical profile and investigate the change in optical scattering properties of the dust as a function of altitude.

Geological measurements at isolated remote sites. Since the vehicle easily traverses obstacles that rovers cannot, we will be able to sample regions that are geologically interesting but too rugged for surface rovers to reach.

References:

[1] G. Landis, D. Linne, and D. Taylor, "A Mars Rocket Vehicle with In-situ Propellant Production," AIAA-2000-3120, to be presented at 36th Joint Propulsion Conference, Huntsville AL, July 17-19 2000. [2] D. Kaplan, J. Ratliff, R. Baird, G. Sanders, K. Johnson, P. Karlman, K. Juanero, C. Baraona, G. Landis, P. Jenkins, and D. Scheiman, "In-Situ Propellant Production on Mars: the First Flight Demonstration," presented 30th Lunar and Planetary Science Conf., Houston TX, Mar 15-19 1999.

MATE AND DART: AN INSTRUMENT PACKAGE FOR CHARACTERIZING SOLAR ENERGY AND ATMOSPHERIC DUST ON MARS. Geoffrey A. Landis[1], Phillip Jenkins[1], David Scheiman[1], and Cosmo Baraona[2], [1]Ohio Aerospace Institute, NASA Glenn Research Center mailstop 302-1, Cleveland OH 44135, e-mail geoffrey.landis@grc.nasa.gov, [2]NASA Glenn Research Center mailstop 302-1, Cleveland OH 44135, e-mail cosmo.baraona@grc.nasa.gov.

Introduction: The MATE ("Mars Array Technology Experiment" [1]) and DART ("Dust Accumulation and Removal Test" [2]) instruments were developed to fly as part of the MIP experiment on the [now postponed] Mars-2001 Surveyor Lander [3]. MATE characterizes the solar energy reaching the surface of Mars, and measures the performance and degradation of solar cells under Martian conditions. DART characterizes the dust environment of Mars, measures the effect of settled dust on solar arrays, and investigates methods to mitigate power loss due to dust accumulation.

MATE

MATE Purpose: Until Mars Pathfinder landed in July 1997, no solar array had been used on the surface of Mars. The MATE package is intended to characterize the environment of Mars in order to gather baseline information required for designing power systems for long duration missions, and to quantify the performance of advanced solar cells on the surface of Mars.

MATE will measure the performance of five different individual solar cell types and two different solar cell strings.

MATE Solar Characterization Sensors: To measure the properties of sunlight reaching the Martian surface, MATE incorporates two radiometers and a visible/NIR spectrometer.

The radiometers consist of multiple thermocouple junctions using thin film technology. These devices generate a voltage proportional to the solar intensity. One radiometer measures the global broadband solar intensity, including both the direct and scattered sunlight, with an approximately 130° field of view. The second radiometer incorporates a slit to make a measurement of the direct (unscattered) intensity radiation. The direct radiometer can only be read once per day, with the sun overhead.

The spectrometer measures the global solar spectrum with a 256-element silicon photodiode array, sensitive in the visible range (300 to 1100 nm), and an second InGaAs photodiode array, sensitive to the near infrared (900 to 1700 nm). The spectrometer range covers 86% of the total energy from the sun, in approximately 5 nm resolution. Each photodiode array has its own fiber optic feed and grating.

Although the purpose of the MATE is to gather data of utility to designing solar arrays for Mars surface power systems, the radiometer and spectrometer measurements are expected to also provide important scientific data in characterizing the properties of suspended atmospheric dust.

DART

DART purpose: Dust deposition could be a significant problem for photovoltaic array operation for long duration missions on the surface of Mars. Measurements made by Pathfinder showed 0.3% loss of solar array performance per day due to dust obscuration [4,5]. Thus, dust deposition is the limiting factor in the lifetime of solar arrays for power systems on Mars, and developing design tools to mitigate this deposition is important for extended mission duration.

The DART experiment is designed to quantify dust deposition from the Mars atmosphere, measure the properties of settled dust, measure the effect of dust deposition on the array performance, and test several methods of mitigating the effect of settled dust on a solar array. Although the purpose of DART is to gather information critical to the design of future power systems on the surface of Mars, the dust characterization instrumentation on DART will also provide significant scientific data on the properties of settled atmospheric dust.

Dust characterization on DART is done by two instruments: the dust microscope and the "MAE" commandable dust cover. The dust mitigation tests on DART consist of two tests: the tilted cell tests, and the electrostatic dust repulsion test. In addition, DART will have a set of sun position sensors.

Microscope. The DART microscope is a fixed-focus microscope, which images a transparent glass settling plate from below. As atmospheric dust settles on this settling plate, it is imaged. The microscope uses a 40X objective, which focuses onto a 512x512 pixel focal plane array. The microscope resolution is about 0.5 microns.

Total mass of the microscope is 200 grams.

The microscope is intended to furnish information about the size distribution of the settled dust. Since settled dust may be different in character from the dust, which remains suspended in the atmosphere, this information is of considerable interest to the design of dust mitigation strategies. For the larger particles, the DART microscope will also yield shape information.

Dust coverage measurement. The "MAE" dust cover is based on the experiment flown on Pathfinder [4], and consists of a transparent plate onto which dust settles. This plate is located above three small solar cells, used in short-circuit current mode as solar intensity measurement in three wavelength bands. A mechanism allows the cover to be rotated away from the cells. Comparison of the cell output with the dust-covered plate in position and removed measures the dust coverage independently of other changes in the cell performance or the atmosphere. By taking a spectrum of the sunlight through the MAE settling plate, we can also obtain a transmission spectrum of the settled dust.

Dust Mitigation Experiments. Measurements of the camera window on the Viking lander showed no dust adhering to the vertical surface. Observations of the thermal shell of the Viking landers seemed to show that dust also did not build up on the tilted surfaces. Unfortunately, no quantitative measurement of accumulation could be made. A high priority is therefore to see whether tilted solar cells avoid accumulation of dust, and to find what angle is required to avoid dust coverage. The tilted cell measurement consists of solar cells tilted at 30°, 45°, and 60°, plus a horizontal control, plus a solar cell tilted at 30° with low friction (diamond-like carbon) coating.

Martian atmospheric dust is expected to be charged. In order to test whether electrostatic fields can be used to mitigate the deposition of dust on solar arrays, the electrostatic experiment will test three configurations. A high-voltage solar cell provides a potential of about 80 volts to a transparent conductor on the front surface of the solar cell coverglass. Three configurations are tested: positive potential applied to the cell cover, negative potential applied to the cell, and transverse field across the cell. These will be compared to the control cell with no applied potential.

Sun Position Sensors. Finally, the DART experiment includes a set of three sun position sensors, each consisting of a cylindrical lens focusing light onto a 512-element linear photodiode array. The sun position sensors have a mass of 18 grams each.

Summary: The MATE and DART experiments, designed for the Mars-2001 Surveyor Lander mission, contain a capable suite of sensors which provide both scientific information as well as important engineering data on the operation of solar power systems on Mars. MATE will characterize the intensity and spectrum of the solar radiation on Mars. DART will measure the dust accumulation rate, the transmitted spectrum of the dust, and will image individual settled particles to determine the size distribution and the particle shape, as well as gathering information on electrostatic properties.

References:

[1] D. Scheiman, C. Baraona, D. Wilt, G. Landis and P. Jenkins, "Mars Array Technology Experiment (MATE) on the Mars-2001 Lander," *2nd World Conference on Photovoltaic Energy Conversion, Vol. III,* Vienna, Austria, July 1998, 3675-3678. [2] P. Jenkins, G. Landis, *et al.*, "Status of the Dust Accumulation and Removal Technology Experiment for the Mars 2001 Lander," Conf. *Record of the 5th International Conference on Mars,* Pasadena CA, July 18-23 1999. [3] D. Kaplan, J. Ratliff, R. Baird, G. Sanders, K. Johnson, P. Karlman, K. Juanero, C. Baraona, G. Landis, P. Jenkins, and D. Scheiman, "In-Situ Propellant Production on Mars: the First Flight Demonstration," presented 30th Lunar and Planetary Science Conf., Houston TX, Mar 15-19 1999. [4] G. Landis and P. Jenkins, "Measurement of the Settling Rate of Atmospheric Dust on Mars by the MAE Instrument on Mars Pathfinder," *J. Geophysical Res. , Vol. 105*, No. E1, 1855-1857 (Jan 25, 2000).. Presented at the AGU Fall meeting, San Francisco CA, Dec. 6-10 1998.

ANAEROBIC NITROGEN FIXERS ON MARS. B. G. Lewis, Dept. of Civil Engineering, Northwestern University, Evanston, IL 60208. Email: b-lewis@northwestern.edu

The conversion of atmospheric nitrogen gas to the protein of living systems is an amazing process of nature. The first step in the process is biological nitrogen fixation, the transformation of N_2 to NH_3. The phenomenon is crucial for feeding the billions of our species on Earth. On Mars, the same process may allow us to discover how life can adapt to a hostile environment, and render it habitable.

Hostile environments also exist on Earth. For example, nothing grows in coal refuse piles due to the oxidation of pyrite and marcasite to sulfuric acid. Yet, when the acidity is neutralized, alfalfa and soybean plants develop root nodules typical of symbiotic nitrogen fixation with *Rhizobium* species possibly living in the pyritic material. When split open, these nodules exhibited the pinkish color of leghemoglobin, a protein in the nodule protecting the active nitrogen-fixing enzyme nitrogenase against the toxic effects of oxygen. Although we have not yet obtained direct evidence of nitrogenase activity in these nodules (reduction of acetylene to ethylene, for example), these findings suggested the possibility that nitrogen fixation was taking place in this hostile, non-soil material. This immediately raises the possibility that free-living anaerobic bacteria which fix atmospheric nitrogen on Earth, could do the same on Mars. The Martian atmosphere includes 2.7 % N_2 and 0.13% O_2 [1] -- if N-fixing anaerobes can adapt or be engineered to thrive in Martian "soil", one can postulate an eventual build up of organic nitrogen for subsequent use by other forms of life. Anaerobic photosynthetic bacteria that fix atmospheric nitrogen might, ideally, also build up oxygen in the Martian atmosphere, but the intense UV radiation reaching the Martian surface would preclude survival outside of a light-transparent shield. Sulfate-reducing bacteria such as *Desulfovibrio*, living beneath the surface with possible access to water adsorbed on fine particles, seem more promising in this regard. Free-living anaerobic diazotrophs on Earth include *Archaeoglobus* [2], the bacillaceae *Clostridium, Desulfatomaculum*, and *Desulfovibrio* [3] and the photosynthetic bacteria *Thiorhodaceae, Chlorobacteriaceae,* and *Athiorhodaceae* [4].

N_2-fixing organisms on Earth, whether free-living or symbiotic, have a common enzyme, nitrogenase, that mediates the following reaction:

$$N_2 + 8e^- + 8H^+ + nATP \Rightarrow 2NH_3 + nADP + nP_i$$

Splitting of the N_2 molecule is an energy-intensive process; 8 to 16 moles of ATP are required to fix 1 mole of N2. This value is not easy to determine because the partitioning of electrons between the two electron acceptors H^+ and N_2 depend on conditions such as ATP concentration, pH, substrate and substrate concentration. The electron donor in many of the systems studied is ferredoxin; where iron is deficient, flavodoxin has been found to substitute. Nitrogenase is a two-protein enzyme consisting of an Fe fraction and an FeMo fraction. The initial steps in the action of nitrogenase consist of the reduction of the Fe-protein, activation of the Fe-protein by Mg-ATP, followed by electron transfer between the nitrogenase proteins [5]. Under some conditions, V can substitute for Mo. Thus for starters, the N_2-fixing sulfate reducers require Fe, Mo, Mg, and an oxidant (sulfate or sulfite on Earth), N_2 in the atmosphere, and the absence of oxygen.

Elemental analyses of the Martian surface indicate an iron concentration (as Fe_2O_3) of 18 mass % and Mg as MgO of 8 mass % [1]; molybdenum and vanadium are possibly present, estimated to be about 1.7 ppm and 162 ppm, respectively [6], within the range of their occurrence in terrestrial soils. Sulfur is present at about 5 mass % (expressed as SO_3) in the "soil" from Pathfinder data [1]. Sulfite reduction is more thermodynamically favorable than sulfate reduction. In fact, reduction of sulfate by sulfate-reducing bacteria will not occur without initial activation by ATP and the formation of the intermediate adenylyl sulfatase [5]. Peroxides (whose presence in the Martian surface is inferred from interpretation of the Viking lander life-detection experiments) may serve as oxidants, albeit rather strong ones. These conditions, and effects on N_2-fixation can be tested experimentally in laboratory microcosms.

Another crucial component for survival of anaerobes is a carbon source. For *Desulfovibrio* and other N-fixing microorganisms, organic acids (e.g., malate, succinate, pyruvate, and lactate) and amino acids serve the purpose on Earth. On Mars, however, atmospheric CO_2 is the only abundant source of carbon known to be present (about 95% of its atmosphere). There is conflicting evidence that at least one species of *Desulfovibrio* could use CO_2 as a carbon source, but this result has more recently been attributed to mixotrophy, a coupled reaction [7]. Here, again, is an avenue for experimentation.

Peroxides in the Martian soil, intense UV radiation, extreme cold, and the absence of liquid water bode ill for the survival and evolution of Earth-like organisms on Mars. Yet, even on Earth we find microorganisms in the most unlikely places: in the core of a nuclear reactor, in a concentrated sulfuric acid copper solution, in thermal springs, in vents of volcanoes, and in Antarctica. Study of the physiology and biochemistry of anaerobic microorganisms, particularly the sulfate reducers, in a simulated Martian environment can demonstrate whether such life, or genetically engineered versions thereof, could survive and grow on Mars. Nitrogen-fixers on Earth have evolved several methods for protecting the enzyme nitrogenase against toxic oxygen: development of internal membranes, incorporation into plant nodules, formation of heterocysts, utilization of oxygen scavengers and reductants, and buffers such as leghemoglobin. On Mars, where O_2 is essentially absent, the N_2-fixers may find Heaven.

References: [1] Lodders, K. and Fegley, B., Jr. (1998). The Planetary Scientists' Companion. Oxford University Press, N.Y. [2] Thauer, R.K. and Kunow, J. (1995). In Barton, L. Sulfate-Reducing Bacteria, Biotechnology Handbooks 8. Plenum Press, N.Y. [3] Silvester, W. and Musgrave, D. (1991 In Dilworth, M.J. and Glenn, A.R. Biology and Biochemistry of Nitrogen Fixation. Elsevier, N.Y. [4] Mulder, E.G. (1975) in Stewart, W.D.P. Nitrogen fixation by free-living microorgansms, Cambridge University Press, 3-28. [5] Cypionka, H.. (1995) Chapter 6 in Biotechnology Handbook 8. [6] Morgan, J. and Anders, E. 1979. *GCA* 43:1601- 1610. [7] Postgate, J.R. (1984). The Sulphate-Reducing Bacteria. Cambridge University Press.

A Remote Sensing/Geographic Information Systems Approach in the Selection of Mars Sites of Biological Interest

Lobitz, B. M. [1], Wood, B. L. [2], Averner, M. [2], and McKay, C. [2]

1 Johnson Controls World Services, NASA Ames Research Center, Moffett Field, CA
2 NASA Ames Research Center, Moffett Field, CA

The search for extinct or extant life on Mars is the search for past or present liquid water, respectively. There are numerous signs of past liquid water on Mars in the form of dry river valleys, paleolakes, and their associated flow and sediment patterns. While some of these features are recent (Amazonian, 1.8 billion years ago to present), there is no evidence that any are currently flowing. Liquid water on the surface would only be possible at those sites with sufficiently high temperatures and pressure. The key to the selection of sites on Mars to search for evidence of life is the search for the presence of water.

An approach to this problem is the use of remotely sensed data incorporated in a geographic information system (GIS). A GIS is a computer-based system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e., data identified according to their locations. In planetary studies these data are acquired from remote sensing (RS) platforms (orbiters). These data are co-registered layers and, through the use of GIS analysis functions, areas on these layers can be selected as a function of the information desired. Our work used existing data layers from the Viking and Mars Global Surveyor missions to determine where water could be possible in liquid form on the Martian surface, based on the phase diagram for water.

Mars has water as ice in the polar caps and vapor in the atmosphere. The atmosphere often contains enough water to be saturated at nighttime temperatures. Frost was observed on the ground at the Viking 2 Lander site at 48°N and presumably forms at other high latitude sites as well. Water as liquid on the surface of Mars has not been observed and theoretical considerations suggest liquid water would not form on the surface due to low pressures and temperatures (Paige and Ingersoll, 1985). However, the pressures at the Viking sites (Tillman, et al., 1993) were always above the triple point of liquid water (6.1 mbar) and surface temperatures on Mars have been observed to rise above freezing (Keiffer et al., 1977). Thus, it is expected that pressure and temperature combinations exist on Mars what would allow liquid water. A map of such sites might reveal locations of the most recent liquid water activity or sites of possible transient liquid formation at the present epoch.

We have determined the locations and periods on Mars in which the pressure and temperature conditions are thermodynamically consistent with liquid water. The pressure at each location throughout the Martian orbit was determined from the Viking 2 Lander pressure record and extrapolated to other locations using the MOLA topographic data assuming hydrostatic equilibrium. Such analysis does not indicate that liquid water would be present at these sites but may indicate that such sites are locations of interest in terms of possible geochemical and biological activity of liquid water. Improved topography, atmospheric, surface composition, and other data from future Mars missions may provide better, more refined data layers that could be used to improve the RS/GIS analysis. This analysis could be used to guide site selection for increasingly finer-scale exploration and analysis on Mars.

DEEP INTERNAL STRUCTURE OF MARS AND THE GEOPHYSICAL PACKAGE OF NETLANDER. P.Lognonné[1], D.Giardini[2], B.Banerdt[3], and the NL-SEIS team, V.Dehant[4], J.P.Barriot[5], and the NEIGE team, G.Musmann[6], M. Menvielle[7], and the MAGNET team. [1]IPGP, 4 Avenue de Neptune, 94100 Saint Maur des Fossés Cedex, France, lognonne@ipgp.jussieu.fr, [2] ETH, Zurich, Switzerland, [3] JPL, Pasadena, USA, [4] ORB, Bruxelles, Belgium, [5] GRGS, Toulouse, France, [6] TUBS-IMG, Braunschweig, Germany, [7] CETP, Saint Maur des Fossés, France.

Introduction: Our present understanding of the interior structure of Mars is mostly based on the interpretation of gravity and rotation data, the chemistry of the SNC meteoroids, and a comparison with the much better–known interior structure of the Earth. However geophysical information from previous missions have been insufficient to determine the deep internal structure of the planet. Therefore the state and size of the core and the depth and type of mantle discontinuities are unknown. Most previous seismic experiments have indeed failed, either due to a launch failure (as for the Optimism seismometer [1] onboard the small surface stations of Mars 96) or after failure on Mars (as for the Viking 1 seismometer). The remaining Viking 2 seismometer [2] did not produce a convincing marsquake detection, basically due to too strong wind sensitivity and too low resolution in the teleseismic frequency band. After almost a decade of continuous activity and proposals (ESA Marsnet, NASA Mesur, and ESA-NASA InterMarsnet) the first network mission to Mars, NetLander (NL), is expected to be launched between 2005 and 2007 [3]. One of the main scientific objectives of this 4-lander network mission will be the determination of the internal structure of the planet using a geophysical package. This package will have a seismometer, a magnetometer and a geodetic experiment, allowing a complementary approach that will yield many new constraints on the mineralogy and temperature of the mantle and core of the planet.

The core: The size, mineralogy and thermal state of the ***core*** is a crucial parameter for understanding a planet's accretion and internal structure. Assuming that the Martian core has a near adiabatic temperature gradient, it will be possible to model the core with very few parameters. If the core is liquid, such parameters will be the ***density***, the ***adiabatic bulk modulus***, the core-mantle boundary ***radius*** and ***temperature*** (the shear modulus being by definition zero for a liquid core). Other parameters, such as the partial derivatives of the density and adiabatic modulus with respect to temperature and pressure can be found with high-pressure laboratory experiments for candidate core mineralogies. Therefore, the determination of the mineralogy and temperature of the core is essentially equivalent to the determination of the 4 independent parameters described above and will be performed by the seismometer and the geodesy experiment.

The Mantle: One of the main goals will be the determination of the location of the main mantle discontinuities and the estimation of the temperature profile in the mantle. The shape of thediscontinuites will provide information on the iron content, which smoothes out the discontinuities over a thickness of one to two hundred kilometers [12]: such smoothing will be resolved by the seismic velocity model.

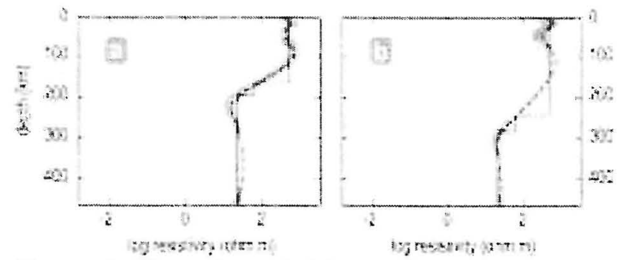


Figure 1: Figure for resistivity profile, after [10a]. The solid line shows the input model. The shaded area shows the recovered model. Simulations take network geometry and noise into account, for. a lithosphere thermal thickness of 200 km (a) and 300 km (b) respectively

The electrical resistivity a complementary source of information. It varies greatly with respect to thermodynamic conditions such as temperature,the percentage of conductive fluids within the solid matrix (molten rock, water-rich fluids) and the thickness of the lithosphere. Electromagnetic soundings will thus determine the thickness of the cold resistive lithosphere *[Figure 1]*, and the presence (or absence) of partial melting at the base of the Mars lithosphere.

The NL Seismometer: This has a 2 kg mass allocation and consists of a 2 axis Very-Broad-Band seismometer, a 3+1 axis Short Period Broad Band seismometer and various environmental sensors. Sensitivity is better than 5 10^{-10} $ms^2/Hz^{1/2}$ in the band 1 mHz-1Hz and better than 5 10^{-9} $ms^2/Hz^{1/2}$ in the band 1Hz-50Hz. The seismometer science objective is the determination of the mean values of the shear and bulk elastic moduli and seismic attenuation as a function of depth through the recording of seismic and tidal data. These seismic data will consist of the recording of the natural quakes of the planet, whose occurrence frequency was estimated from surface fault observations [4] and from theoretical estimates of the thermo-elastic cooling of the lithosphere [5].

The detection zone of P and S waves for an example network configuration shows that the detection efficiency is very high in the Tharsis area, where small quakes of seismic moment of 10^{14} Nm might be detected *[Figure 2]*. Both diffraction and attenuation, the latter extrapolated from the Phobos' secular acceleration measurement by [6], are taken into account. The experiment will also search for continuous seismic and tidal signals. These signals are associated to two continuous sources. The first will be the tide of the small Martian satellite, Phobos, A detailed discussion of the sensitivity of the signal with respect to structure are given in [8]. The second source, in the frequency band of 0.1-10 mHz, is the atmospheric turbulence. As shown by [9], such excitation processes on Mars might be almost as strong as those observed on the Earth. More details on the NetLander seismic experiment can be found in [10b].

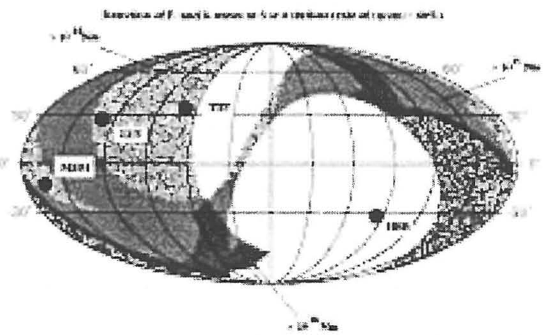


Figure 2: Detection area for Marsquakes. See details in [7].

NEIGE and Geodesy: The NEIGE experiment (see details in [10,11]), will make it possible to answer the question of whether the ***core*** is liquid or solid, as well as yielding other detailed information on Mars' interior by an improved measurement of the precession rate. It will use the NL telecom system, with 0.280 Kg mass allocation for specific components. NEIGE will also measure variations in the length of day, and therefore constrain mass exchange between the polar caps and the atmosphere. The size and state of the core will be determined by accurate measurements of Mars' ***nutation***. In particular, the nutation could be influenced by a resonance effect between the free nutation of a liquid core (FCN) and the nutation driven by the Sun with frequencies at multiples of the orbital frequency [*See Figure 3*]. The FCN observation will also directly lead to the determination of the CMB density jump. Improvement by a factor of 2.5 to 5 of the moment of inertia provided by NEIGE will reduce the present error to a level useful for real constraints in the core temperature and mineralogy.

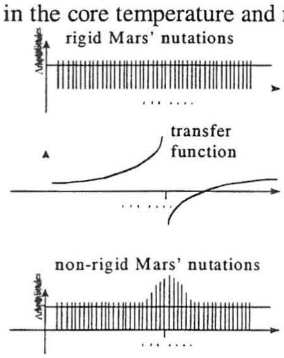


Figure 3: Schematic representation of the effect of the FCN resonance on the forced nutations.

MAGNET: The Magnetic Sounding experiment is composed of a network of identical triaxial subminiature fluxgate magnetometers, with a resolution of 0.025 nT and a mass allocation of 0.235 Kg (see details in [10c]). The attitude of the vector components of each triaxial fluxgate sensors will be known with an absolute accuracy of few tenths of a degree in both vertical and horizontal directions. The impedance of the internal structure will be deduced from the ratio of the vertical component of the magnetic field and the horizontal gradients of its horizontal component. With the simultaneous recordings from three or more stations available, the impedance will be estimated from the frequency-wave vector spectrum of the electromagnetic field using a high-resolution method developed by [10d]

References: [1] Lognonné et al., 1998. The Seismic Optimism Experiment, *Plan. Space Sciences*, **46**, *739-747.*; [2] Andersonet al., 1977. Seismology on Mars, *J. Geophys. Res.*, **82**, 4524-4546. ; [3] Harri et al., 1999. Network Science Landers for Mars, Adv. Space Res, **23**, No 11, pp 1915-1924. [4] Golombek et al., 1992. A prediction of Mars Seismicity from surface Faulting, Science, **258**, 979-981. [5] Phillip., 1991. Expected rate of marsquakes. In Scientific Rationale and Requirements for a Global Seismic Network on Mars. LPI Tech. Rept. 91-02, Lunar and Planetary Inst., Houston. pp. 35-38; [6] Lognonné and Mosser, 1993. Planetary Seismology, **14**, 239-302, *Survey in Geophysic*. [7] Mocquet, 1998. A search for the minimum number of stations needed for seismic networking on Mars, *Plan. Space. Science*., **47**, 397-409, 1999. [8] Dehant et al., 2000, "Computation of Mars' transfer function for nutation tides and surface loading.", in: Proc.SEDI meeting, Phys. Earth planet. Inter., **117**, 385-395. [9] Kobayashi and Nishida., 1998. Continuous excitation of planetary free oscillations by atmospheric disturbances, *Nature*, **395**, 357-360., [10a] Mocquet and Menvielle, Seismic and electromagnetic signature of phase transitions in the mantle of Mars, [10b] Lognonné et al., The NL VBB seismometer, [10c] Menvielle et al., Contribution of magnetic measurements onboard NL to Mars exploration, [10d] Pinçon et al., Geomagnetic induction using the NL network of magnetometers, [10 a-d] in Mars International Conference and Micro-Missions/Netlander Workshops proccedings, Planetary Space Science, Special issue, in press; [11] Van Hoolst et al., 2000, "Sensitivity of the Free Core Nutation and the Chandler Wobble to changes in the interior stucture of Mars.", in: Proc. SEDI meeting, *Phys. Earth planet. Inter.*, in press; [12] Mocquet et al., 1996. Theoretical seismic models of Mars: the importance of the iron content of the mantle. *Planet. Space Sci.*., **44**, 1251-1268.

PRECISION NAVIGATION FOR A MARS AIRPLANE. James W. Lowrie, SAIC Center for Intelligent Systems, 8100 Shaffer Parkway, Suite 100, Littleton, CO 80127, e-mail: jlowrie@cis.saic.

Introduction: The rough Martian terrain significantly impedes high speed travel by wheeled vehicles and much of it is simply inaccessible given the capability of typical rover designs. Airplanes however, have much greater range and can provide access to scientifically interesting terrain that is inaccessible to landers and rovers. Moreover, they can provide coverage of a large portion of the surface and return high resolution images and science data not practical from orbiting spacecraft. Precise navigation on Earth requires a constellation of satellites such as GPS or a network of precisely located and calibrated ground beacons, an approach that is impractical for Mars exploration in the near future. In order to realize the benefits of airplane exploration on Mars, a precision navigation system is required. Such a system also provides a high degree of autonomous capability because it enables:

- Accurate overflight of specifically targeted sites.
- Hazard avoidance in low altitude flight.
- The collection of "focused" science data which reduces overall data volume and supports an optimized data return strategy
- Accurate spatial and temporal correlation of acquired science data with orbiter observations.
- A geodetically referenced site survey capability.
- A soft landing capability by providing in-flight landing site selection and terminal guidance.
- Return to a base station following flight.
- Precise placement of science probes and future navigation beacons.

SAIC's Center for Intelligent Systems (SAIC-CIS) leverages on experience from unmanned vehicle research to propose a concept for an intelligent landmark navigation system that relies on autonomous real-time recognition of visible surface features during flight

Technical Approach: Our concept as described herein, assumes an independently deployed system that doesn't rely on a lander spacecraft for delivery to Mars because it is the most stressing case for a navigation system. Upon entry into the Martian atmosphere, an airplane will initially descend through the atmosphere using an aeroshell / parachute deceleration system. After deceleration, the airplane will separate from the aeroshell and perform a pull-up maneuver to achieve level flight. The autonomous navigation system will then allow the airplane to follow a precise path relative to the planet's surface. Our technical approach relies on a mixture of image processing techniques to resolve both altitude and navigation position in a local coordinate frame.
The navigation system will process images from a primary imaging sensor to determine altitude and recognize landmarks. This data will be filtered with measurements from a barometric altimeter, inertial measurement unit (IMU) and air speed indicator to generate an airplane navigation state. These elements duplicate the functionality of a GPS receiver on terrestrial vehicles. Each of the major navigation elements is further discussed in the following sections.

Altitude Determination – A single camera on a mobile platform provides stereo vision by imaging the same region from two different positions. The primary science camera can thus determine altitude, which reduces cost and complexity by eliminating the need for a radar altimeter. There are three stages to the altitude determination process: algorithm initialization, initial altitude estimate, and ongoing updates. During algorithm initialization, the system acquires a first video frame and extracts high contrast features from the predicted overlapping region. The feature extraction process is repeated in the second image and a stereo correspondence operator applied. Constant operating conditions between frames, such as sun angle and illumination, allows for intensity correlation to establish correspondence at a 1 Hz rate. The resulting disparity estimates for the subimage are condensed into a single range estimate. The geometry in this configuration provides a range resolution on the order of +/- 10 meters to maintain a 2000-meter airplane altitude.

Landmark Tracking - The large initial uncertainty and limited airplane flight time make it necessary to refine the airplane position quickly to conserve resources and achieve an optimal flight path. Accurate vehicle position is obtained by correlating camera images obtained on the airplane with *a priori* geodetically referenced image data acquired from the Mars Surveyor Orbiter. This is known as landmark based position estimation.

The first position estimation is the most critical, because it represents the largest uncertainty and search area size, thereby imposing the most stringent requirements on the flight processor. Once the initial estimate is determined, the location of the next observable landmark can be predicted. The subsequent correlation-based position refinements are simplified because the improved navigation estimate provides knowledge of what landmark to look for. With a decreased search area, the correlation can work at higher resolutions producing more accurate position estimations. Our multi-resolution, correlation-based landmark position estimator will refine vehicle position to within 10 meters.

Our initial algorithm consists of a pre-flight component and runtime component. The pre-flight element uses existing Mars Surveyor images corresponding to the entry ellipse for generation of the *a priori* landmark chips. An interest operator is applied over the data set to extract key features and reduce volume. A set of image chips representing candidate landmark locations is built around areas of high scene activity. The runtime element begins during flight with the acquisition of images at regular intervals of approximately 3 seconds. The acquired image is rectified to match pixel resolution with the prestored reference chips using the altitude estimate from the navigation filter. The same interest operator will then be applied to the camera image over multiple resolutions and a list of image chips around areas of high scene activity is generated. This set of image chips represents the locations in the image to perform a correlation operation. Each chip in the acquired image will be correlated to all of the prestored chips and the maximal responding pair provides an update vector for the Kalman filter. A preliminary analysis performed using Mars Global Surveyor images indicates the processing time for this correlation is on the order of 1 second on a 650MHz Pentium III processor equating to 4 seconds on JPL's X2000 processor. Table 1 highlights our approach to the landmark navigation problem.

Navigation Filter – Because noise perturbations negatively affect the data being generated by each of the sensor subsystems, a navigation filter is needed to produce robust, accurate position estimates. A Kalman filter will be used to provide optimal estimates of the Airplane's state (position and orientation) by combining the Airplane's equations of motion with the IMU's data into its process update, and using the landmark tracking data as the basis for its measurement updates. We have implemented a preliminary filter and the along-track and cross-track errors were calculated for representative sensor noise profiles in a typical Mars environment, and subsequently combined into a circular error plot. The results show that the initial (asymmetric) error of 20 kilometers by 5 kilometers quickly reduced down to less than the target minimum error of 10 meters.

Key Technical Issues	Technical Approach
Large initial uncertainty drives large correlation requirements	Multi resolution approach reduces data volume Correlation of individual "chips" dramatically reduces the computational burden over the area based correlation approaches Interest operators limit correlation to high interest "chips" Interest operators reduce the bits required to represent a pixel
Limited throughput	Approach is compatible with the X2000 processor
Limited memory	Interest operators reduce the bits required to represent a landmark thereby reducing the associated memory requirements
Landmarks in the error ellipse must be matched at the camera frame rate to assure initial reference	Multi resolution approach uses lowest resolution for initial match to minimize throughput requirements Subsequent matches are performed at higher resolution and yield higher accuracy measurements

Table 1 - Multi-Resolution Landmark Tracking is Feasible with the X2000 Computer

COOPERATIVE ROBOTICS AND THE SEARCH FOR EXTRATERRESTRIAL LIFE.

M. L. Lupisella, NASA Goddard Space Flight Center, Code 584, Greenbelt Rd, Greenbelt MD, 20771 mark.lupisella@gsfc.nasa.gov

Introduction: If we think tenuous abodes of life may be hiding in remote extraterrestrial environmental niches, and if we want to assess the biological status of a given locale or entire planet before sending humans (perhaps because of contamination concerns or other motivations) then we face the challenge of robotically exploring a large space efficiently and in enough detail to have confidence in our assessment of the biological status of the environment in question. On our present schedule of perhaps two or so missions per opportunity, we will likely need a different exploratory approach than singular stationary landers or singular rover missions or sample return, because there appear to be fundamental limitations in these mission profiles to obtain the many samples we will likely need if we want to have confidence in assessing the biological status of an environment in which life could be hiding in remote environmental niches. Singular rover missions can potentially accommodate sampling over a fairly large area, but are still limited by range and can be a single point of failure. More importantly, such mission profiles have limited payload capabilities which are unlikely to meet the demanding requirements of life-detection. Sample return has the advantage of allowing sophisticated analysis of the sample, but also has the severe limitations associated with only being able to bring back a few samples.

This presentation will suggest two cooperative robotic approaches for exploration that have the potential to overcome these difficulties and facilitate efficient and thorough life-detecting exploration of a large space. Given the two premises state above, it appears at least two fundamental challenges have to be met simultaneously: coverage of a large space and bringing to bear a sophisticated suite of detection and experimental payloads on any specific location in order to address a major challenge in looking for extraterrestrial life: namely, executing a wide variety of detection scenarios and in situ experiments in order to gather the required data for a confident assessment that life has been detected and to, more generally, cover a wide range of extraterrestrial life possibilities. Cooperative robotics lends itself to this kind of problem because cooperation among the combined capabilities of a variety of simple single function agents can give rise to fairly complex task execution such as the search for and detection of extraterrestrial life.

Shot-Gun Cooperative Robotics: Specifically, a kind of *cooperative robotics shot-gun approach* [1] in the form of tens to hundreds or more small robots, each with a singular life-detection related capability such as detection of water and organics (perhaps even nucleic acids, amino acids and associated chirality, etc.) or such as metabolism measurement experiments, epiflourescence microscopy, molecular sequencing, culturing, sub-surface boring payloads, imaging capabilities, etc. could cover much area and work together by communicating results to the rest of the "swarm" which could then focus on a particular location where a positive result was found.

Mission Scenario Example: An over-simplified search and detection scenario might be something like: first send many small water detection robots, including subsurface boring moles, to a promising area. If water is detected by any one robot, confirm with another robot, and signal to other robots (which could be stored nearby or in orbit, or already deployed nearby, etc.) that have the functionality for the next step which might be detection and measurement of organics. If a promising result is reported, perhaps a metabolism based experiment would be required next, followed by an imaging based robot, and then perhaps more sophisticated functionality such as molecular sequencing or culturing.

In general, this approach can been seen as a kind of biologically inspired exploration methodology, perhaps a form of "swarm intelligence" [2]. The benefit of this kind of approach is that large areas can be covered with diverse detection and experimental techniques which increase the chance of detecting life, and comprehensive data can be obtained in an efficient manner during just one mission opportunity.

. **Cooperative Family Robotics:** A second form of cooperative robotics might be characterized as *cooperative family robotics* where a larger parent rover carries smaller rovers with additional specialized functionality to be deployed as required by the higher level analysis of the more mobile larger rover. A system like this could be large or small. If a larger size were feasible, we'd want to consider the possibility of developing a walk-roll and maybe even hop capability perhaps by designing lockable wheels that can act as feet for walking (e.g. to navigating difficult terrain) and allow for crouching and perhaps hopping, as well as covering large distances by unlocking the wheels for rolling. The primary advantages of this approach are that specialized functions can be selectively deployed in real-time and that the parent rover can act as a central coordinating agent as well as an infrastructural support element for power recharging of the smaller rovers and more sophisticated forms of navigation, drilling, communication, etc.

References:

[1] Lupisella M. L. (1998) "Life" Looking for Life, *Jet Propulsion Laboratory Biomorphic Explorer Workshop*. [2] Bonabeau E., Dorigo M., Theraulaz G.

(1999) Swarm intelligence: from natural to artificial systems. New York: Oxford University Press.

MITIGATING ADVERSE EFFECTS OF A HUMAN MISSION ON POSSIBLE MARTIAN INDIGENOUS ECOSYSTEMS.

M. L. Lupisella, NASA Goddard Space Flight Center, Code 584, Greenbelt Rd, Greenbelt MD, 20771 USA Mark.Lupisella@gsfc.nasa.gov

Introduction: Although human beings are, by most standards, the most capable agents to search for and detect extraterrestrial life, we are also potentially the most harmful. While there has been substantial work regarding forward contamination with respect to robotic missions, the issue of potential adverse effects on possible indigenous Martian ecosystems, such as biological contamination, due to a human mission has remained relatively unexplored and may require our attention now as this presentation will try to demonstrate by exploring some of the relevant scientific questions, mission planning challenges, and policy issues. An informal, high-level mission planning decision tree will be discussed and is included as the next page of this abstract [1].

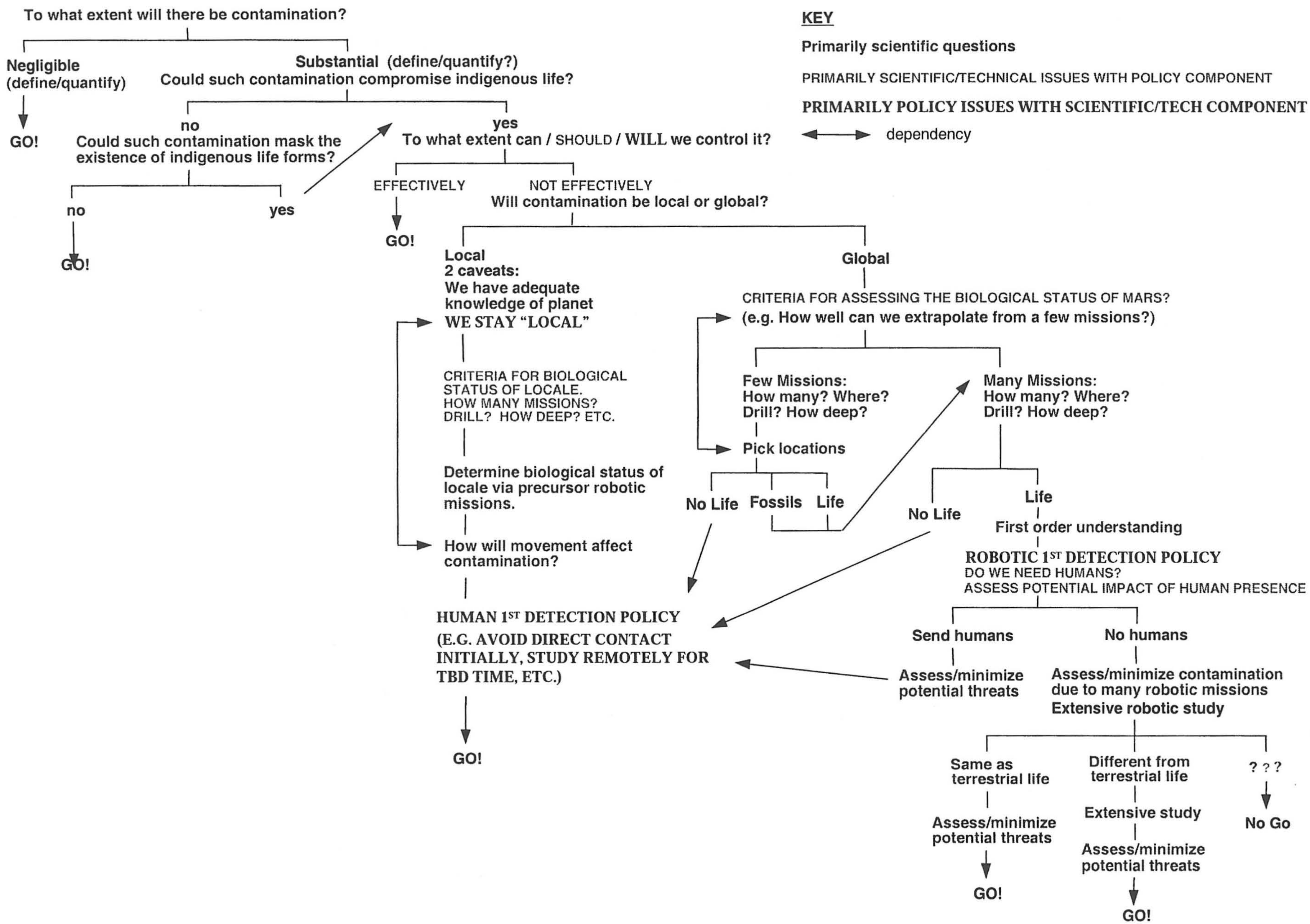
Some of the questions to be considered are: To what extent could contamination due to a human presence compromise possible indigenous life forms? To what extent can we control contamination? For example, will it be local or global? What are the criteria for assessing the biological status of Mars, both regionally and globally? For example, can we adequately extrapolate from a few strategic missions such as sample return missions? What should our policies be regarding our mission planning and possible interaction with what are likely to be microbial forms of extraterrestrial life?

Central to the science and mission planning issues is the role and applicability of terrestrial analogs, such as Lake Vostok for assessing drilling issues [2], and modeling techniques. Central to many of the policy aspects are scientific value, international law, public concern, and ethics. Exploring this overall issue responsibly requires an examination of all these aspects and how they interrelate [3, 4, 5].

References:

[1] Taken from Lupisella M. L. (1999) Ensuring the Integrity of Possible Martian Life, *International Astronautical Federation Congress,* Amsterdam. [2] Lupisella M. L. (1998) A Terrestrial Analog, Presentation/Abstract in *Lake Vostok Workshop Final Report,* National Science Foundation, Washington, D.C. [3] Lupisella M. L. (2000), Humans and Martians, *Earth Space Review,* 9, 1. [4] Lupisella M. L. (1999) The Criticality of Biology's Second Data Point, *NASA Astrobiology Institute Societal Implications Workshop,* NASA Ames Research Center, Mountain View. [5] Lupisella M. L and Logsdon J. (1997) Do We Need a Cosmocentric Ethic? *International Astronautical Federation Congress,* Turin.

Mission Planning Decision Tree for Mitigating Adverse Effects to Possible Indigenous Martian Ecosystems due to a Human Mission



MARS GREENHOUSE EXPERIMENT MODULE, AN EXPERIMENT TO GROW FLOWERS ON MARS. T. K. MacCallum[1], J.E. Poynter[1], and C. P. McKay[2], [1] Paragon Space Development Corp. 810 E. 47th St, #104, Tucson, AZ 85713; [2] NASA Ames Research Center, Mail Stop 245-3, Moffett Field, CA 94035.

Introduction: NASA has entered a new phase of in-depth exploration of the planets where robotic exploration of the Solar System is focusing on in-situ missions that pave the way for human exploration. Creating a human presence on Mars will require specialized knowledge and experience concerning the Martian environment and validated technologies that will provide life-supporting consumables. An understanding of the response of terrestrial organisms to the Martian environment with respect to potential deleterious effects on crew health and changes to biological processes will be paramount.

In response to these challenges an innovative self-contained flight experiment is proposed, which is designed to assess the biocompatibility of the Martian environment by germinating seeds and following their growth through to flowering. The experiment, dubbed Mars Greenhouse Experiment Module (Mars GEM), will be accomplished in a sealed pressurized growth chamber or "Mars Greenhouse". Seeds will be grown in Martian soil and the Mars Greenhouse will provide ultraviolet-radiation protected, thermal-controlled environment for plant growth that actively controls the CO_2 (required nutrient) and O_2 (generated by the plants) levels in the chamber.

The simple, but visually dramatic demonstration of the potential to grow a plant in a man-made environment on the surface of Mars should establish a strong connection between current robotic missions and future human habitation on Mars.

The Objectives and Significant Aspects: The experimental goal is to determine the biocompatibility of the Martian environment such as the atmosphere and regolith. This is to be accomplished by studying the stress sustained by an Earth organism (an angiosperm) grown in Martian soil and possibly Martian CO_2 and water during germination, growth and production of flowers. Such an experiment will determine if exposure has deleterious effects or results in fundamental changes to biological processes. A second objective is to ignite public interest in the exploration and possible future colonization of Mars and elsewhere in the solar system.

NASA has a long tradition of flying technology demonstration missions. Once a technology has been tested on Earth it is important that we gain technical and psychological reassurance by demonstrating that something works on Mars. Pathfinder was such a mission. A module capable of growing plants from seed is a biological demonstration mission similar to plans to test physical/chemical oxygen production from atmospheric carbon dioxide on Mars.

There are many reasons to send flowers to Mars. It would be highly symbolic. These plants would be the first organisms from Earth to grow, live and die on another world. They would be true biological pioneers, an important step for life from Earth as it begins its expansion beyond the planet of origin. More practically, a plant growth module would test the toxicity of the Martian environment in a very direct way. If Martian CO_2 and water are used, the experiment would demonstrate the use of Martian atmosphere components in a greenhouse. These are essential steps toward a full-scale greenhouse to support a human base. The growth of a plant in the Martian environment would help alleviate concerns about dangerously contaminating the Earth by the return of Martian samples by showing that the soil and atmosphere are compatible with life. In all these respects a plant growth module would be a first biological precursor to human exploration of another planet.

The Technical Feasibility: Due to planetary protection requirements and the inherent constraints imposed by a pressurized growth chamber, the plant life support system must be completely materially closed. Paragon Space Development Corporation has performed design studies including plant requirement definition, thermal analysis, regolith collection and dissemination, nutrient and water delivery, seed delivery, CO_2 and O_2 measurement and control, and pressure control. The chamber and subsystems have undergone preliminary design studies and all parameters (mass, size, electrical power, data etc.) can be met using a growth chamber that can be supported as an instrument package on a Mars-01 type lander. The chamber weighs approximately 3.5 Kg, is 17 cm wide by 19 cm high by 25 cm long, and uses less than 16 W-hrs during operational hours. No power is required during the darkness of night.

Planetary protection issues have been studied in depth to ensure that designs meet all criteria for eliminating the risk of contamination of the Martian surface with Earth borne life. The planetary protection guidelines do not explicitly prevent the controlled transport of biological materials to Mars and the use of biological materials in controlled experiments aboard spacecraft. The seeds of the plants would be treated in such a way as to minimize the risk of transport of bacteria. In addition, the sealed chamber is sterilized prior to transportation and treated with high levels of antibiotics and antifungal agents during the experiment. At the completion of the experiment the entire chamber is sterilized to ensure that no microbial life has survived and that all bacteria have been eradicated. Growing a flower on Mars would not contaminate the planet or compromise any future scientific study of the planet.

The plant proposed for the experiment is *Arabidopsis thaliana,* which is used extensively in laboratory gene expression and physiology studies. Thus a large body of knowledge exists with regards to its requirements and propagation. Phenotypes are available that have low light intensity requirements, dwarf plant sizes, short inflorescence, with 45 days to flowering and senescence. The plant will be selected and possibly genetically manipulated to tolerate elevated levels of free-radicals expected in Martian soil and thus can serve as a biosensor for measuring oxidative stress. Further genetic engineering can be performed using Green Fluorescing Protein whereby each plant can indicate the presence or absence of specific stress factors such as toxic levels of metals, high salinity etc. The plants' growth and flowering would be monitored using the lander camera and a camera internal to the growth chamber.

The vessel has an antechamber with a door to the Martian atmosphere to allow the planting bed to be filled with Martian regolith. Once the exterior door is sealed the chamber is pressurized and the soil hydrated before being moved into the greenhouse. Current designs use only that portion of the atmosphere that enters the antechamber from the Martian atmosphere while the door is open. Further design studies need to be performed to determine whether all the CO2 and water used in the experiment can be derived from the Martian atmosphere while conforming to the power and mass limitations of a mars lander.

The greenhouse is constructed with a combination of transparent aerogel and phase change material. A thermal model has been made which shows that the proposed method of heat storage and release maintains the temperature within requirements without the need for a powered heat source at night.

Through 6 years of in-depth work in the field of closed biological systems and biological systems made for space use, Paragon has developed innovative concepts for CO2 and O2 control. These systems allow for an entirely sealed growth chamber with small volume requirements, and reduce the amount of gases required for delivery to the plants from pressurized canisters. An atomic level model has been made that tracks the movements of carbon, hydrogen and oxygen within the system. The model demonstrates the need for daily release of CO2 and nightly storage of CO2 due to plant metabolic processes, which the Paragon system accomplishes with no moving parts and low energy requirements. No energy is required at night for O2 storage.

Summary: For most of us life is the reason that Mars is interesting. We go to Mars to search for the possibility of life early in Martian history when that planet had water and to determine if Mars may be a home for life in the future.

The proposed Mars Green House Experiment Module is conceived to provide important scientific data and to validate exploration technology as a precursor to human missions. The experiment provides for an exceptional opportunity for public education and outreach. It is technically feasible and the maturity of design studies show that a Mars GEM could be used to send life to Mars on the next lander.

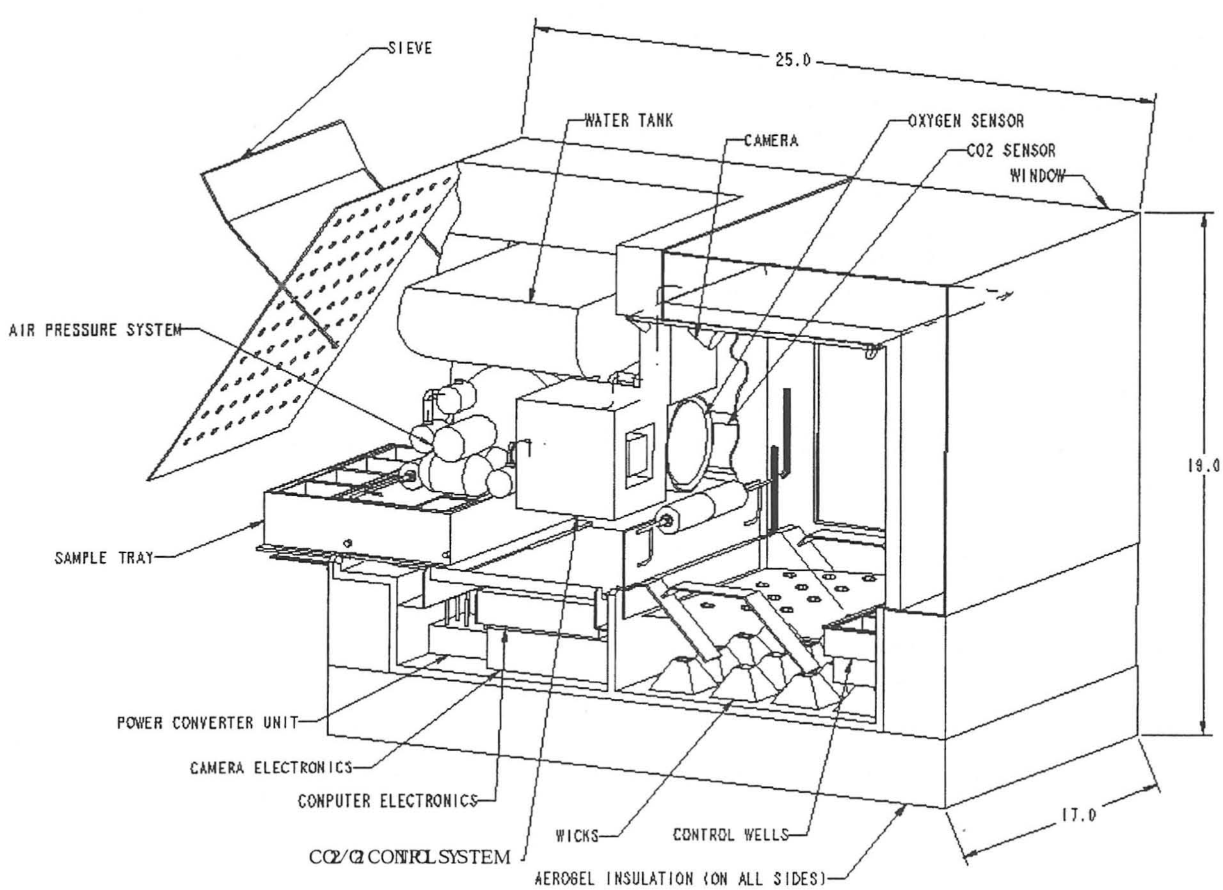


Figure 1. Mars GEM Design Concept

MOLECULAR AND HIGHER PRECISION ISOTOPIC MEASUREMENTS OF THE MARS ATMOSPHERE AND SUBSURFACE VOLATILES. P. R. Mahaffy[1], S. K. Atreya[2], T. C. Owen[3], H. B. Niemann[1], J. Jones[4], and S. Gorevan[5], [1]Code 915, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA, [2]Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, 2455 Hayward Street, Ann Arbor, MI 48109 USA, [3]University of Hawaii, Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822 USA, [4]Jet Propulsion Laboratory, M/S 157-507, 4800 Oak Grove Drive, Pasadena, CA 91109 USA, and [5]Honeybee Robotics 204 Elizabeth Street, New York, New York 10012 USA.

Introduction: In response to the question "what to do next" at Mars we explore the value of a **high precision insitu measurement of isotopic and trace gas constituents in the atmosphere combined with a similar analysis of gas extracted from near surface rocks and soils.** The scientific goals are to advance our understanding of the evolution of the Martian atmosphere and to search for fossils of past geochemical conditions. One element of this program that ties directly to the goals of the Astrobiology Program will be a sensitive search for simple or complex organic molecules contained in the atmosphere and in the solid phase. The broad chemical and isotopic analysis planned insures that a highly successful program will be carried out even if no organics are detected. We will demonstrate that the technology to carry out this program is presently in hand.

Scientific Goals: Three principal areas are addressed by the investigation proposed:

(1) precise isotopic composition of the well mixed atmosphere including all noble gases and common elements in different molecular reservoirs. The measurements will constrain models of the loss of a portion of the atmosphere to space and subsurface reservoirs. For example, the $^{36}Ar/^{38}Ar$ ratio was not well constrained by the Viking GCMS experiment. Precise measurements of all the krypton and xenon isotopes allow comparison with the trapped gas in the SNC meteorites and in material from future sample return missions.

(2) The isotopic and chemical composition of volatiles contained in rocks and subsurface clays and soils. These measurements will reveal the nature of these materials (for example, identify carbonates or sulfates from thermal degradation to CO_2 or SO_2), constrain the nature of the present atmosphere/surface exchange, and may reveal molecules chemically bound when the climate was substantially different.

(3) The search for trace species in the atmosphere and evolved from solids such as orgnics. For example, the present upper limit to the methane atmospheric abundance can be extended by several orders of magnitude by these measurements and a Viking-like search for complex organics carried out this time from well below the highly oxidized surface materials.

Measurement Requirements: These broad scientific objectives outlined give rise to stringent measurement requirements. Isotope ratios in trace (ppb) noble gas species must be measured to the per mille level. Chemical conversion of major species must be carried out isolate isotopic ratio differences in different molecular reservoirs. Trace atmospheric species present at the mixing ratios down to sub parts per billion must be analyzed.

Technology Status: Fortunately, the technology to meet these requirements presently exists as a result of development for recent planetary missions such as the Cassini Huygens GCMS [1] (in cruise), the Champollion ST4 comet nucleus lander (mission recently canceled) and development support from NASA for the Mars specific measurement issues. Under the ST4 development program, for example, a Sample Collection and Transport Mechanism (SATM) was developed and tested to penetrate either hard or soft materials to a depth of 1-2 meters and return a sample to a pyrolysis chamber for GCMS chemical analysis. The Huygens GCMS that will encounter Titan's atmosphere in 2004

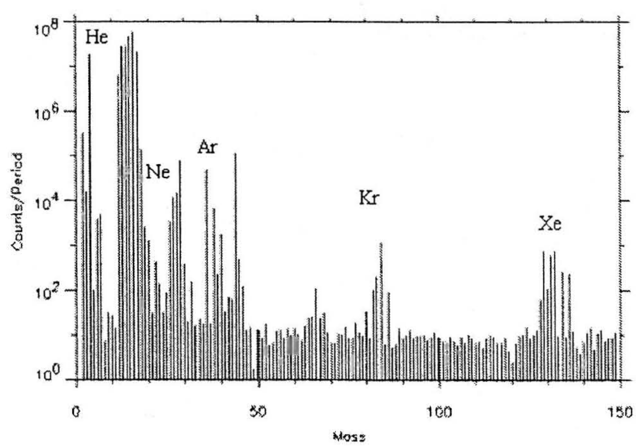


***Figure 1** Noble gas isotopes at Jupiter*

will carry out exactly this type of analysis using GCMS technology considerably advanced from the Viking era. The range of chemical analysis would require multiple subsurface samples and chemical and physical enrichment and reactive processing of atmospheric constituents to produce a gas suitable for introduction to either the MS directly or to the inlet of the GCMS. The isotopic precision required has been demonstrated in the laboratory using flight like instrumentation. Heritage for this type of experiment also comes from the Galileo Probe mission. Detection of noble gas isotopes at Jupiter [2, 3] using the Probe Mass Spectrometer is illustrated in Figure 1. The effectiveness of the gas separation used at Jupiter is illustrated by this figure since each xenon isotope is present in the Jovian atmosphere at a sub ppb mixing ratio.

Example Mission Design: The preliminary defi-inition of exactly such an experiment sized to the micromission carrier presently under study and soft landed on Mars by a Montgolfier balloon was recently carried out in a joint GSFC/JPL/Honeybee Robotics

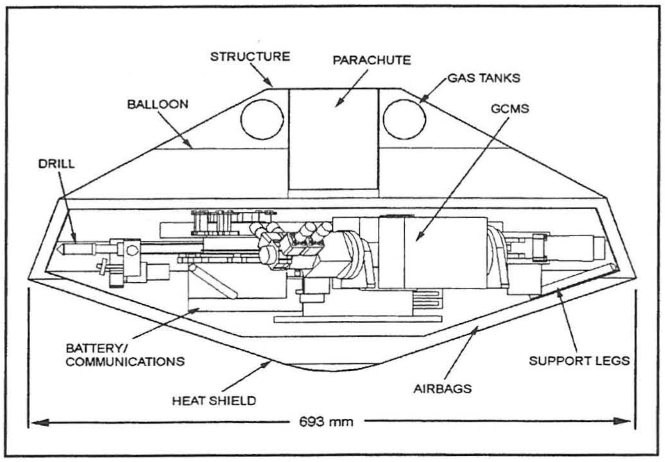


Figure 2 *An example of a small payload in the stowed configuration for delivery to the Martian surface.*

study [4, 5]. Figure 2 illustrates the configuration of a GCMS, based payload delivered to the surface of Mars by such a system. Although, the Montgolfier can deliver the payload with an arbitrarily low vertical velocity, the payload is dropped and protected by small airbags just above the surface to avoid damage due to a wind driven horizontal velocity. The stowed SATM (shown) rotates into a vertical position after deployment and can extend to more than twice its stowed length to penetrate more than one meter in this micromission delivered payload.

Enhancements to the Example Mission: The small payload delivered to the surface in this study contained the SATM, the GCMS, and a camera. It was designed to obtain atmospheric and subsurface samples only at the landing site. Enhancements to this concept could be enabled by moving outside of the constraints of the micromission delivery system to allow a considerably extended measurement lifetime and the option of roving to multiple sites across the surface. Particularly, interesting are the advanced rover techniques presently being prototyped by JPL that use inflatable tires to maximaze efficiency in traversing rocky terrain and covering large distances in a relatively short time period. An SUV-sized, 20-kg inflatable rover prototype has been developed [6] that can readily climb over 0.5 m rocks, thus enabling rapid transportation (~5 km/hr) over 99% of the Martian surface with relatively low mobility power requirements (< 20 watts). Together with advanced deep subsurface sampling technology under development by Honeybee Robotics a wide region search for subsurface water and organic species can be significantly advanced.

Conclusions: In spite of its negative result on organic molecules, the Viking lander mass spectrometer measurements in 1978 provided data that was the key to achieve the understanding that the origin of the SNC meteorites was most likely Martian. Similarly significant advances in our understanding of the evolutionary history of Mars are expected whenever we decide to finish the job that the Viking GCMS started. Priority should be given to now measuring with high precision of the isotopic composition of the Martian atmosphere and chemical analysis of gases evolved from samples collected well below the highly oxidized surface. Insitu measurements by surface landers can achieve these measurements and be carried out at a small fraction of the cost of a sample return mission. Such missions are logical precursors to these more ambitious sample return efforts.

References:

[1] Niemann et al., ESA-SP 1177, 85, 1998) [2] Mahaffy, P.R., H. B. Niemann, A. Alpert, S. K.Atreya, J. Demick, T. M. Donahue, D. N. Harpold, and T. C. Owen, Noble Gas Abundance and Isotope Ratios in the Atmosphere of Jupiter from the Galileo Probe Mass Spectrometer, JGR Planets 105, 15061 - 15071 (2000). [3] Owen, T., P.R. Mahaffy, H.B. Niemann, S. Atreya, A. Bar-Nun, T. Donahue, I. de Pater, A low-temperature origin for the planetesimals that formed Jupiter, Nature 402, 269, 1999. [4] Mahaffy, P. R., D. Harpold, H. Niemann, S. Atreya, S. Gorevan, G. Israel, J.L. Berteaux, J. Jones, T. Owen, F. Raulin, Mars Solar Balloon Landed Gas Chromatograph Mass Spectrometer, Proc. International Symposium on Mars Exploration Program and Sample Return, P4/S1(70) (1999). [5] Jones, J., P. Mahaffy, Jose Rivera and S. Gorevan, GCMS/Montgolfiere Micromission to Mars, Proc. 4th International Conf. on Low Cost Planetary Missions, Laurel (1999). [6] Jones, J. and J.J. Wu, "Inflatable Technology for Robotics", Space 2000 Conf., Albuquerque, NM, (2000).

RETURNED SAMPLES: THE EXPECTATIONS AND IMPLICATIONS. G. Manhès, J. L. Birck and C. J. Allègre, Laboratoire de Géochimie et Cosmochimie, IPGP, 4 Place Jussieu, 75252 Paris Cedex 05, France (birck@ipgp.jussieu.fr).

Introduction: Before the exploration of Mars, the Apollo and Luna programs are the only example of a planetary invesgation including a sample return. The context is somewhat different but the scientific logic to get the best knowledge of a planet from the available remote instruments or returned sample, is broadly similar. The purpose of the present paper is to illustrate some constrains of the geological exploration of a planet. Although there has been 30 years that the fisrt moon samples were returned to the earth for study and that there will be around another ten years before the Mars sample return, there is still a number of measurement methods applied on lunar samples within terrestrial labs which have to day no equivalent counterpart in remote operated instruments. This does not mean that there was no progress but that despite the advances in automation and the power increase in computer process control, there are methods which require either large instruments because of the nature of physics or the presence of the human operator because of the complexity of the analytical procedures. This holds for a constant level of investigation capacity which of course is not the case as the evolution of laboratory instruments has also been tremendous over the last decades in mostly two directions: improvement of the potential of existing instruments and the introduction of new instrumentation concepts e.g. atomic force microscope or ICPMS. Adaptation of the instruments to unexpected properties of the sample is also much faster and efficient for the scientific return when samples are already on Earth.

Guidelines: Within the frame of the dominant objectives focused on life, climate and resources, time is an essential parameter. There is no way to describe the past and present processes within and on the surface of Mars without having a time scale. Major issues are also the identification of the planetary reservoirs and their evolution through time. This holds for the main geological units: core, mantle, crust but the fate and history of water is tightly connected to these. The time scale is established on measuring the formation ages of rocks and this can be achieved only on returned sample with high precision isotopic measurements on actual rock samples. The sample size depends on the conservation state of these chips or whatever cores but cm sized rocks at least for a number of them is a requirement. This can work on much smaller samples, depending on composition, but cannot be downscaled beyond limits because of the atomic nature of matter; thermodynamic statistics set the minimum number of atoms to be measured to reach the required level of precision. This leads to a miminum range in size from 10's of mg to 1gm.. Why is that so ? Dating is done with many complementary techniques, each with its own applicability based on the physico-chemical nature of the samples and its preservation. As martian samples are going to be different of what we know from meteorites and the moon and as some degree of alteration is present, it is absolutely necessary to cross check the ages obtained with several radiochronometers used in isotopic geology.

The essential difference between Moon samples and the future samples returned from Mars is sample availability. Typical Apollo samples sizes were in the kilogram range. Luna samples were somewhat smaller (~100g) but with less variability and they were less extensively investigated. Such amounts allowed to run the different experiments on separate splits of the sample and also to duplicate most of the experiements. On the MSR samples this will be no more possible. Expected amounts are in the gram range that is about three orders of magnitude less. Instruments and the skill of the experimentators has improved both in precision and in sensitivity but this does not compensate for this reduction. As stated hereabove downsizing the sample used in each experiment has its limits or will degrade the quality of the data relative to the possibilities of the instruments. The analytical procedures for isotopic work and also some of the trace element work also implies the destruction of the sample. Taking all this into account, the only processing strategy is to combine most if not all of the experiments into a single integrated procedure which measures all elements from one aliquot of the starting sample. This has already been partly done in the past for example combined Rb-Sr and Sm-Nd measurement or combined measurements of the whole rare-earthes group but not at the global scale. This is now an absolute requirement and has to be prepared over the coming years. The implications are of two kinds: establishment of very reliable procedures and blank reduction.

Firstly the reliability should be high enough that duplication of measurement should not be neccessary. This has greatly been achieved already for the Moon samples, the only endeavour is to repeat this with the redesigned analytical scheme. Also the constraints in natural samples are variable from element to element and the highest requirements are on those which have to be measured with high precision and having low concentration. In the very same sample separates at least some of the other elements will be in sufficient amounts to do several repeats. The validity of the procedure has to be tested on actual samples the composition of which is close of what is expected to be returned from Mars. The terrestrial medium has such a variety of rocks that there should be no difficulty to find well documented equivalents. But the robustness of the methods can also be investigated for strongly different compositions as actual returned samples may be far from expectations and also to take into account the variability of the rocks if an "intelligent" sampling program can be performed.

Secondly integrated procedure imply either more complex preparation or separation chemistry with intrinsically higher procedural blanks when compared to simple parallel analysis. Bringing blanks to levels where they do not alterate the precision of the measurement naturally follows the testing process on actual samples. Every reagent or material in contact with the samples has to be inspected before entering into the analytical procedure. These inter-elemental cross-checks have also to be performed for every tracer added to the sample e.g. the enriched isotopes for the isotope dilution measurements. This is a time consuming process which may take a few years and in which almost all elements have to be followed closely.

Additional comments: Non destructive observations can normally be applied extensively without harm for future investigations. Nevertheless in most cases some preparation of the sample is involved like polishing or coating which actually destroys the samples for many other experiments. It means simply that the same experiment can be carried out several times on exactly the same sample. Real non destructive observations allowing almost all further experiments on the same sample are in fact seldom: X-Rray examination is one of the most harmless. The sampling itself is already part of this process as an experienced field geologist can give some parameters of their composition within a given context. This is also what is expected from in-situ experiments connected to an "intelligent" sampling strategy. Before going to the destructive experiments, samples will be characterized with non destrutive methods for mineralogy and petrography as well as for biological signature but this will also produce significant information on the chemistry of the samples. In taking these data into account together with the elements teh most difficult to measure, the management of the sample distribution among the different experiment can be even more closely trimmed to a minimum consumption.

The importance of bringing back rocks or rock chips has also to be emphasized to obtain reliable ages which are cross checked with several dating methods. Theses ages can not be obtained an wind blown dust. This dust represents a planetary average which may be biased by unknown sorting factors (size, hardness, density...).

With samples in the range of grams there are elements which can already not be measured optimally even when using the whole sample: Os is one example. If it happens that basalts from Mars are less radiogenic than terrestrial ones, higher precisions will be required and there will not be enough Os atoms in the sample to reach them. But this is a speculation for the time being.

DREAM (DISPOSITIF DE RETOUR D'ÈCHANTILLON D'ATMOSPHÈRE MARTIENNE) : MARTIAN ATMOSPHERE SAMPLE RETURN. B. Marty[1], E. Chassefière[2], P. Agrinier[3], A. Jambon[3], M. Javoy[3], B. Lavielle[4], K. Marti[5], M. Moreira[6], D. Pinti[7], F. Robert[8], Y. Sano[9], P. Sarda[7]. [1]CRPG/CNRS 15 Rue Notre-Dame des Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy Cedex, France, bmarty@crpg.cnrs-nancy.fr, [2]Centre d'Etudes Terrestres et Planétaires, IPSL, Paris, [3]Laboratoire de Physico-chimie des Fluides Géologiques, Université P. et M. Curie and IPG Paris, [4]Laboratoire de Chimie Nucleaire Analytique et Bioenvironnementale, Centre d'Etudes Nucléaires de Bordeaux-Gradignan, [5]Department of Chemistry & Biochemistry, University of California, San Diego, [6]Laboratoire de Géo et Cosmochimie, IPG, Paris, [7]Groupe de Géochimie des Gaz Rares, Paris XI-Orsay, [8]Muséum National D'Histoire Naturelle, Paris, [9]Departement of Earth and Planetary Sciences, Hiroshima University.

Introduction: The elemental and isotopic composition of the Martian atmosphere are poorly known from the analyses of VIKING. The similarity between this composition and that of trapped gas inclusions in SNC meteorites led to the conclusion that SNC were from Mars and allowed scientists to refine estimates of Mars atmospheric composition. Due to the large uncertainties remaining on the elemental and isotopic compositions of C, O, N and noble gases, extremely important problems concerning the origin and evolution of the Martian hydrosphere and atmosphere as well as for the geodynamical evolution of Mars cannot be resolved with available measurements. Specifically, the following processes require a precise knowledge of the Martian atmospheric composition : Chemical and isotopic zoning in the solar nebula; Accretion processes; degassing of the planetary interior (catastrophic or/and continuous), contributions of chondritic and cometary material; solar wind input; atmospheric evolution (T. Tauri, thermal, sputtering, impact erosion). Geological features of the presence of liquid water and its present-day absence, the relative abundance of CO_2 and N_2, the relative abundances of noble gases, isotopic composition of hydrogen, nitrogen, argon and xenon are all puzzling features which would be explained in a comprehensive model.

Why do we need to retun an atmospheric sample in a separate container ? We propose to develop a Martian atmosphere sampling experiment which will allow the return to Earth's laboratories of well characterized atmospheric samples. These samples will permit the analysis of major and minor volatiles with high precision. Such precision, notably of the order of 1 % on Xe isotopes, is critically required to resolve important issues on the timing of Mars atmosphere-mantle interactions as well as on the irradiation history of Mars.

The return of Martian atmosphere samples does not substitute to an in-situ measurement but instead supplement it, both experiments having flaws and advantages. Among the advantages of an in-situ measurement (see the PALOMA project [1]), such experiment will allow to measure with reasonable accuracy atmospheric gases from an unlimited reservoir and through time (e.g. seasonal variations), whereas the laboratory measurement will permit specific investigations on key parameters for which analytical precision will be out of reach by a automated measurement. Notably, the twin experiments will allow to crosscheck the data. Finally, in case of failure of one of the two experiments, we expect to have nevertheless access to an atmospheric composition data set much better than available at present.

The low temperature release (< 200°C) of volatiles from Martian rock has now experimentally been observed (without introducing shock effects as expected in rock containers). Therefore, the exchange and mixing of rock gas and container atmosphere has to be expected. As the indigenous isotopic signatures differ dramatically from atmospheric gases, this would severely compromise the isotopic and elemental information on the evolution of volatiles. It may not only compromise, but invalidate the information.

Only small sample containers (2-3cc) are required for elemental analyses; these would provide unfractionated elemental data. Therefore, duplicate containers (and duplicate sampling on two missions) should be considered.

Heavy rare gases and also important minor molecular species which can be concentrated by low-T adsorption in adsorbers (which need to be tested and selected!) would increase the information content significantly. This is especially relevant for high precision isotopic work (e.g. Xe) and for species that are relevant for studies of exchange/loss mechanisms (H2O, N2). These samples obviously will require additional containers.

References: [1] Jambon A. et al., this meeting.

The Next Generation MOD: A Microchip Amino Acid Analyzer for Detecting Extraterrestrial Life

R. A. Mathies and L. D. Hutt, Department of Chemistry, UC Berkeley, CA 94720; J. L. Bada and D. Glavin, Scripps Institution of Oceanography, UC San Diego, La Jolla, CA 92093-0212, F. J. Grunthaner and P. J. Grunthaner, NASA JPL, 4800 Oak Grove Drive, Pasadena, CA 91109

The MOD (Mars Organic Detector) instrument which has selected for the definition phase of the HEDS package on the 2005 Mars Explorer Program spacecraft is designed to simply detect the presence of amino acids in Martian surface samples at a sensitivity of a few parts per billion (ppb). An additional important aspect of amino acid analyses of Martian samples is identifying and quantifying which compounds are present, and also distinguishing those produced abiotically from those synthesized by either extinct or extant life. Amino acid homochirality provides an unambiguous way of distinguishing between abiotic vs. biotic origins (Bada and McDonald 1996). Proteins made up of mixed D- and L-amino acids would not likely have been efficient catalysts in early organisms because they could not fold into bioactive configurations such as the a-helix. However, enzymes made up of all D-amino acids function just as well as those made up of only L-amino acids, but the two enzymes use the opposite stereoisomeric substrates. There are no biochemical reasons why L-amino acids would be favored over D-amino acids. On Earth, the use of only L-amino acids in proteins by life is probably simply a matter of chance. We assume that if proteins and enzymes were a component of extinct or extant life on Mars, then amino acid homochirality would have been a requirement. However, the possibility that Martian life was (or is) based on D-amino acids would be equal to that based on L-amino acids. The detection of a non-racemic mixture of amino acids in a Martian sample would be strong evidence for the presence of an extinct or extant biota on Mars. The finding of an excess of D-amino acids would provide irrefutable evidence of unique Martian life that could not have been derived from seeding the planet with terrestrial life (or the seeding of the Earth with Martian life). In contrast, the presence of racemic amino acids, along with non-protein amino acids such as α-aminoisobutyric acid and isovaline, would be indicative of an abiotic origin, although we have to consider the possibility that the racemic amino acids were generated from the racemization of biotically produced amino acids (Bada and McDonald 1995).

A potential impediment to the search for life on Mars is the forward contamination of the planet with either terrestrial organisms, or more likely terrestrial biomolecules. This problem would be of great importance in assessments of whether there are any amino acids indigenous to Mars. Because of the distinctive L-enantiomer signature of amino acids associated with terrestrial life, chiral amino acid analyses can be used to monitor the level of forward contamination of Mars which occurs during the course of planetary exploration. This requires that amino acid analysis data be acquired as early as possible in the Mars exploration program in order to provide a useful baseline data set for comparison with future analyses. A long range monitoring program would be critical in assessing forward contamination during the eventual human exploration of Mars.

A relatively new technology which shows promise for spacecraft-based amino acid enantiomeric analysis is microchip-based capillary electrophoresis (μCE). With μCE, both the identity and enantiomeric composition of amino acids can be determined at sub-part-per-billion levels. The μCE based analyses are about an order of magnitude faster than analytical methods such as conventional CE and high performance liquid chromatography (HPLC). Such short analysis times are an inherent advantage for robotic *in situ* measurements carried out from a spacecraft. In addition, μCE has a detection limit more than three orders of magnitude better than conventional HPLC. Thus, proportionally smaller samples (~100 pl or 10^{-10} l) can be analyzed, another important advantage for *in situ* spacecraft based instruments.

Under a project funded by the Planetary Instrument Definition and Development Program (PIDDP), a μCE chip system has been used to explore the feasibility of using such devices to analyze for amino acid enantiomers in extraterrestrial samples (Hutt *et al.* 1999). The test system consisted of a folded electrophoresis channel (19.0 cm long x 150 mm wide x 20 mm deep) that was photolithographically fabricated in a 10 cm-diameter glass wafer sandwich, coupled to a laser-excited confocal fluorescence detection apparatus providing sub-attomole ($<10^{-18}$ mole) sensitivity. The μCE analysis system consists of a stack of wafer scale components which individually provide the liquid flow channels, the capillary separation zones, the electrophoretic controls, the fluid logic and the detection system. This μCE system is more than an order of magnitude smaller in size than conventional laboratory bench top amino acid analytical instruments. Analysis times with μCE are on the order of a few minutes compared to almost an hour for HPLC-based analysis.

A critical aspect is that enantiomeric ratios can be rapidly and accurately determined using the microfabricated CE chip instrument. Using a sodium dodecyl sulfate/γ-cyclodextrin pH 10.0 carbonate electrophoresis buffer and a separation voltage of 550 V/cm at 10• C, baseline resolution is observed for the enantiomers of valine, alanine, glutamic acid, and aspartic acid in only 4 minutes (see **Figure 1**). Enantiomeric ratios of amino acids extracted from the Murchison meteorite using this μCE chip system closely matched values determined by HPLC (Hutt *et al.* 1999).

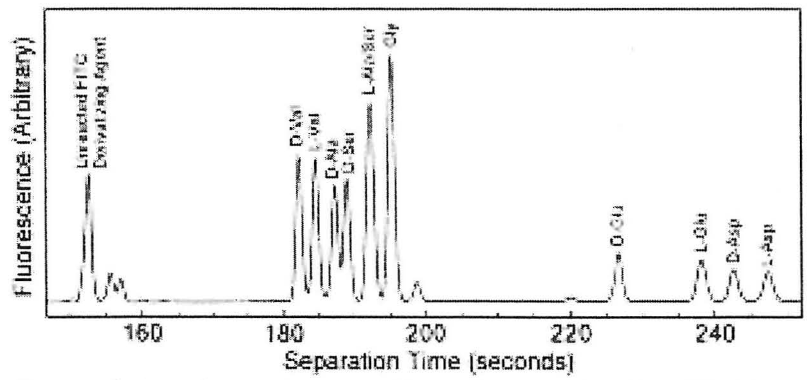


Figure 1: Baseline resolution of several amino acid enantiomers using the μCE chip system (taken from Hutt *et al.* 1999).

For spacecraft based analyses, a microfluidics-based sample processing system is required in order to delivery an amino acid extract suitable for analysis by a μCE system. In a design scheme presently being tested, amino acids are first extracted from a sample by a hot water/acid hydrolysis procedure. The aqueous extract obtained by this procedure is frozen and then sublimed at Mars ambient pressure onto a cold finger. The sublimed ice/amino acid mixture is thawed and collected into a reservoir interfaced with a μCE chip instrument. With this design, no desalting is required, thus eliminating a procedure which requires reagents and ion-exchange chromatography.

The reduced time, resources, and sample requirements for microfabricated CE chip instruments translate into a significant reduction in mass, power, and volume. With an estimated mass of ~1 kg, a volume of ~1000 cm^3 and a power requirement of ~2 W, the μCE chip system provides a compact, low-mass instrument suitable for a wide variety of *in situ* exobiology applications.

Bada, J. L. and McDonald, G. D. 1995. *Icarus* **114**, 139-143.
Bada, J. L. and McDonald, G. D. 1996. *Anal. Chem.* **68**, 668A-673A.
Hutt, L. D, Glavin, D. P., Bada, J. L. and Mathies, R. A. 1999. *Anal. Chem.* **71**, 4000-4006.

SAMPLES FOR INVESTIGATIONS ON PAST AND/OR CURRENT BIOLOGICAL ACTIVITY ON MARS. M-C Maurel[1], [1]Institut Jacques Monod, Tour 43, 2 Place Jussieu 75251 Paris Cedex, France and the French C.S.E.E.M. e-mail : maurel@ijm.jussieu.fr

Introduction: Multi-disciplinary groups of biologists emerged in France as a result of two workshops (June1999 and January 2000) devoted to Mars sample return. The search based on the assumption that key engredients for life, liquid water and a source of energy are evidenced on ancient Mars, they are currently developing strategies to detect possible extinct and/or extant life on Mars. We can be sure that biosignatures of life, if there are, will be rare and to confirm this potentially controversial discovery the most sensible idea to address numerous questions is to bring safely to Earth laboratories selected samples from the surface and subsurface of Mars. It may be essential in order to claim extraordinary scientific conclusions to permit to do new and complete investigations. Most of them will be conducted under quarantine.

Objectives.
Mars exploration and samples analysis present a fundamental interest either for the scientists seeking for apparition of life on Earth and elsewhere, and for those interested by the definition of life, the understanding, the process and development of livings within ecosystems, and also those concerned by molecular mechanisms within the living cell, their adaptations and their evolution. Numerous fields are getting involved in these topics, for instance genomics, virology, microbiology, biochemistry, molecular biology, biophysics, studies of non-conventional organisms etc. This list is far from being exhaustive. Furthermore, combinatorial methods permit today the investigation of potential diversity of new macromolecules, and the emergence of a new molecular biology, perfecting new molecular tools etc [1, 2].
On the other hand, our capacity to detect life is an important issue. If there is no extant life, there is no biological risk.
Detection of life and biological tests for the risk will be done during a quarantine phase. Two main lines seem to have priority:
- Definition of a quarantine protocol including characterization analysis, detection and determination of hazards.
- Perfecting level 4 laboratories methods.
After quarantine, microbiologists, virologists and biologists experts in manipulation and detection of pathogen agents (including non-conventional ones) would be strongly involved in confinement and sample's conservation, in the short or long term.
In France, a level 4 laboratory (P4) [3] in Lyon, well-equipped with up-to-date facilities, and a confinement place to receive Mars samples are available.

The French biological community is strongly involved in the national activities in preparation of the Mars samples return mission. The demonstration was done with the large and expert participation to January 2000 workshop.
Some central themes were defined :
- definition of favorable conditions for life preservation:
The surface of Mars today is generally inhospitable to life. It is cold and dry and possibly there is a lot of salts. These conditions are favorable for the conservation of life and therefore for the preservation and identification of macromolecules or cellular structures, in particular in saline microenvironments. Many disciplines are involved in these topics, such as macromolecule's physico-chemistry, geochemistry, geomicrobiology etc..
- Interactions between micro-organisms and environments [4,5] could involded multidisplinaries teams of microbiologists, biochemists, geneticians and physicochemists to define metabolic and ecological limits in which life could have arose and evolved.
- definition of non-destructives manipulation techniques of Mars samples to detect life or bio-signatures and make a dynamical study of biological and bioorganic systems [6].

Perspectives:
Several teams of strongly complementary laboratories are working together in France for :
- The identification and reactivity of bio-organic molecules from the Martian samples. Reactivity means properties experimentally highlighted. This definition include biochemical functions and reactivities, for instance studies of non-genomic peptide synthesis
[7], weak chemical links which characterize biological molecules, identification of blocks of monomers (character-string like), tridimensional structure of polymers etc. In other words everything which make molecular activity.
This new structural biology tightly linked to reactivity requires methodologies combining physical and biochemical approaches. For instance studying decompo-

sition of peroxydes by biological complexes require a complementarity between Raman spectrometry and polarography [8]; SERS (surface enhanced Raman spectrometry) and infrared spectrometry shall allow us to understand polymerization, homologies and structural differences between informational precursors etc. On the other hand, we know today that DNA is robust and it is easy to extrapolate the same property for its precursors. Modeling studies will be performed in vitro using mineral/DNA (or analogs) assemblages to mimic the conditions prevailing on the Martian surface.

Also, the algorithmic theory of complexity and information theory will allow us to formally describe the finite and infinite complexity of sequences of characters. It is then possible to model certain syntactic structures of current genomes and of "non conventional" ones. These theoretical approaches will be experimentally validated using the systems optimized above.

The broad outline of this kind of programme is to optimizise the methodologies and to produce experiments under conditions mimicking those that are characteristic of the planet Mars (irradiation, temperature, pressure, hydrous potential, salts etc.)

- The study of micro-organisms adapted to extreme terrestrial environments in order to set up their biochemical machinery. The kind of adaptations (to energy sources, temperature, radiations etc.) will be useful to identify putative organisms adapted to the constraints of the present or past Martian environment [9].

The use of physical approaches for the study of the states of water and aqueous solutions under different conditions (with and without salts etc.) would be essential to the understanding of the development of living organisms. Furthermore, macromolecules which are the smallest scale of life appearance, are known to be well-conserved within salts [10]. To search for macromolecular signatures on Mars, it is of central interest to study the effects of environment and in particular of salts on the structure, stability, interactions and dynamics of molecules from these extremes.

This two examples are representative of richly multidisciplinary approach with expertise in biophysics, biochemistry, molecular biology and genetic, microbiology of halophile, thermophile and psychrophile organisms, physics of water etc...already working in France.

References: [1] Maurel M-C. and Décout J-L. (1999), *Tetrahedron, 55*, 3141-3182. [2], Benner, S.A., Devine, K.G., Matveeva, L.N., and Powell D.H., (2000), *PNAS*, 97, 2425-2430. [3] http://www.fond-merieux.org/ . make contact with Jacques Grange. [4] Bourrain, M., Achovak, W., Urbain, V., Heulin, T. (1999*). Curr. Microbiol.* 38 (6). [5] Schütz, M., Brugna, M., Lebrun, E., Baymann, F., Huber, R., Stetter, K.-O.,Hauska, G., Toci, R., Lemesle-Meunier, D., Tron, P., Schmidt, C. and Nitschke, W. (2000) *J .Mol.Biol.*, in press [6] V. Toniazzo, B. Humbert, R. Benoît, R. Erre and C. Mustin, (2000) *American Mineralogist*, in press. [7] Maurel, M-C. and Orgel, L.E., (2000), *Origins of life*, in press. [8] Bruston, F. Vergne, J., Grajcar, L., Drahi, B., Calvayrac, R., Baron, M-H., and Maurel, M.C. (1999), *Biochem. Biophys. Res. Commun.* 263, 672-677. [9] Jeanthon,C., L'Haridon, S., Reysenbach, A.L., Corre, E., Vernet, P. Messner, U.W. Sleytr, and Prieur, D. (1999), *Int. J. Syst. Bacteriol.* 49, 583-589. [10] Madern, D., C. Ebel, and G. Zaccaï. (2000), *Extremophiles.4* . in press.

MARTIAN NEUTRON ENERGY SPECTROMETER (MANES). R. H. Maurer[1], D. R. Roth[1], J. D. Kinnison[1], J. O. Goldsten[1], R. Fainchtein[1], and G. Badhwar[2], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, richard.maurer@jhuapl.edu, [2]Johnson Space Center, Houston, TX 77058.

Introduction: High energy charged particles of extragalactic, galactic and solar origin collide with spacecraft structures and planetary atmospheres. These primaries create a number of secondary particles inside the structures or on the surfaces of planets to produce a significant radiation environment. This radiation is a threat to long term inhabitants and travelers for interplanetary missions and produces an increased risk of carcinogenesis, central nervous system (CNS) and DNA damage. Charged partcles are readily detected; but, neutrons, being electrically neutral, are much more difficult to monitor. These secondary neutrons are reported to contribute 30-60% of the dose equivalent in the Shuttle and MIR station (1).

The Martian atmosphere has an areal density of 37 g/cm^2 primarily of carbon dioxide molecules. This shallow atmosphere presents fewer mean free paths to the bombarding cosmic rays and solar particles. The secondary neutrons present at the surface of Mars will have undergone fewer generations of collisions and have higher energies than at sea level on Earth. Albedo neutrons produced by collsions with the Martian surface material will also contribute to the radiation environment.

The increased threat of radiation damage to humans on Mars occurs when neutrons of higher mean energy traverse the thin, dry Martian atmosphere and encounter water in the astronaut's body. Water, being hydrogeneous, efficiently moderates the high energy neutrons thereby slowing them as they penetrate deeply into the body. Consequently, greater radiation doses can be deposited in or near critical organs such as the liver or spleen than is the case on Earth. A second significant threat is the possibility of a high energy heavy ion or neutron causing a DNA double strand break in a single strike.

MANES Instrument Objectives: MANES was proposed in response to AO 99-HEDS-01for additional payloads to fly on the Mars 2003 Lander. The proposal was submitted in August 1999 and was selected for the definition phase in November 1999.

The MANES instrument is partitioned into two channels—the Low Energy Spectrometer (LES) and the High Energy Spectrometer (HES)—which are mounted to a central housing containing the electronics to operate the instrument and provide the spacecraft interface. It will have a mass of 5 kg and measure the Martian neutron spectrum over a large energy range. Specific objectives for MANES are

1) measure the neutron fluence energy spectrum on the surface of Mars over an energy range from 100 keV to 50 MeV with a goal of 20 keV to 100 MeV;
2) monitor both the diurnal and solar cycle time variations in the neutron environment;
3) compare the measured neutron spectra to models that propagate the incident cosmic ray spectrum through the Martian atmosphere and calculate the reflected albedo from the Martian surface;
4) determine the neutron directionality ratio;
5) measure the fluence ratios of protons to alphas to heavy ion groups in the HES anti-coincidence shield for the incident charged particles;
6) from the results, calculate the dose, dose rate, dose equivalent and dose equivalent rate to be expected by astronauts on Mars.

MANES Instrument Design: The LES uses a helium 3 gas tube to measure neutrons in the energy range from 100 keV or less to about 5 MeV. Two of these tubes will be flown with some polyethylene absorber to help determine differences between the propagated and reflected neutron spectra (directionality). The tubes will operate in both the common $^3He(n,p)^3H$ neutron absorption reaction mode and in the elastic neutron scattering mode that monitors the ^3He recoil. The absorption reaction has an energy release of Q=0.764 MeV which is added to the incident neutron energy. The spectrum has peaks corresponding to the most prominent neutron energies plus the Q of the reaction. If a thermal neutron peak is present as at sea level on Earth, it will provide a continuous energy calibration. Modeling and beam facility testing will provide necessary corrections for tube efficiency and the elastic scattering transfer function.

The HES will consist of a pair of 5-7 mm thick, 3 cm^2 lithium drifted silicon detectors ganged together to maximize the number of targets or fractions of a mean free path presented to the natural neutron beam. Charged silicon recoil nuclei, nuclear fragments, protons and alphas are progeny of the neutron-silicon collisions in the detector and their ionization depositions are collected and measured by standard pulse height techniques. Both elastic and inelastic reactions contribute to the total solid state detector efficiency. A thick detector offers increased efficiency which is important as the neutron energy increases to tens of MeV.

The silicon detectors will be surrounded by a CsI cup and plug scintillators that will serve to veto charged particle depositions in the silicon. In addition to using the CsI as an anti-coincidence shield, we will record the light in the CsI with PIN photodiodes to yield information on charged particle ion groups. The plug or puck will face the Martian surface and also be able to record information on the most prominent gamma rays emitted from the soil. Rise time discrimination methodology will be used to distinguish the different types of radiation.

Results: Engineering prototype gas tube and silicon solid state detectors have been tested and evaluated since 1998 under funding from the National Space Biomedical Research Institute (NSBRI) through NASA Cooperative Agreement NCC 9-58. Testing of detectors has been carried out with Cf, PuBe and AmBe radioactive neutron decay/spallation sources and with mono-energetic neutron beams. The Columbia University Radiological Research Accelerator Facility (RARAF) supplied mono-energetic neutrons between the energies of 0.5 and 20 MeV by the use of p-t, d-d and d-t reactions. RARAF is an NIH supported resource center through grants RR-11623 (NCRR) and CA-37967 (NCI).

The ^{3}He gas tube detector has consistently shown the classic responses to both radioactive and beam neutrons. Wall effect, epithermal, recoil and absorption count peaks are readily resolved in the pulse height spectra. For example, for 2.46 MeV neutrons the ^{3}He(n,n)^{3}He elastic recoil reaction produces short rise time pulses while the ^{3}He(n,p)^{3}H absorption/capture reaction produces long rise time pulses. Pulse rise time is used to discriminate between the two effects. The full width at half maximum of the epithermal peak is about 25 KeV and indicative of the LES detector energy resolution. The greater width of the neutron absorption peak is due mainly to the energy spread of the incident neutron beam. Data plots will be presented on these results.

The 5mm thick lithium drifted silicon solid state detector has been evaluated using mono-energetic neutron beams at RARAF. Since the cross section for the neutron capture rection in the gas tube falls precipitously above 1-2 MeV, a more dense detector medium must be used for the higher neutron energies. Neutron energies of 5.9, 14, 16.25 and 18.5 MeV were used to determine the overall efficiency and deposited enrgy spectra. The spectra observed over this energy range show considerable structure since we are in a region where nuclear resonances are prominent. The lowest energy deposition events give a smooth response and are due to the elastic scatter of the incident neutrons from the silicon detector nuclei and extend from our low energy detector cutoff (250 KeV as determined by noise) to 0.133 times the incident neutron energy as determined by the kinematics of the silicon recoil nucleus in the elastic reaction. An intermediate energy deposition region with minor structure is due to the moderately sized recoil fragments in the inelastic collisions including resonance excitation and decay. An example of such a fragment is a magnesium nucleus produced in a neutron-silicon collision that also creates an alpha particle. The high energy end of the deposition spectrum contains significant structure in the form of peaks which have energies up to the incident neutron energy and are due to a superposition of various proton and alpha particle states. The different energies of these peaks are determined by the kinetic energy given the proton or alpha particle in the different inelastic collision excitation and decay states. Again data plots will be presented.

The efficiency of the silicon detector is governed by the total cross section for neutron-silicon reaction as a function of energy. The experimental efficiency for the 5mm thick detector in the neutron energy range of 5.9 to 18.5 MeV was determined to be 4-5%. We compared our experimental results with both NASA deterministic (2) and Dept. of Energy Monte Carlo (3) models and found very good agreement for efficiency. This agreement indicates that MANES can efficiently measure neutrons in the 5-20 MeV range. Since the models predict the efficiency to be greater than 3% out to neutron energies of 100-150 MeV, we expect our bulk silicon detector to be useful at these higher energies as well.

Modeling: We are using the CERN GEANT4 software suite (4) to model our experimental results and run virtual experiments on our detector configuration. The GEANT4 code uses the Evaluated Nuclear Data Files (ENDF) as input for all particle reactions. It tracks all products of reactions and conserves energy at each reaction point. We have reproduced both the experimental detector efficiency and high energy deposition events for our 18.5 MeV runs at RARAF and are in the process of completely simulating all our RARAF experiments. Our ultimate objective is to develop a complete transfer function for MANES to deduce the most probable incident neutron spectrum.

References:

(1) *Workshop on Secondary Neutrons in Space*, USRA, Houston, September 28-30, 1998.

(2) J. Shinn, NASA Langley, private communication, 1999.

(3) M. Chadwick, LANL, private communication, 1999.

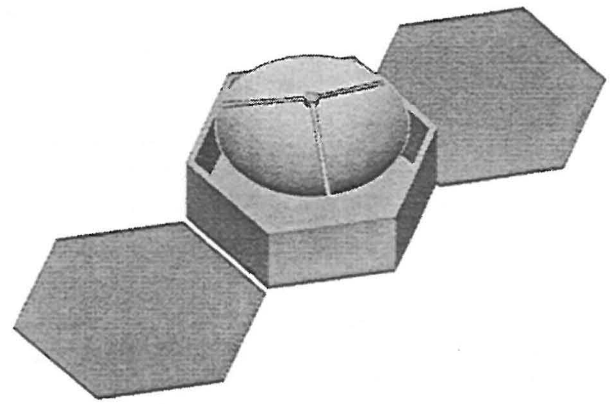
(4) H-P. Wellisch, CERN, private communication, 2000.

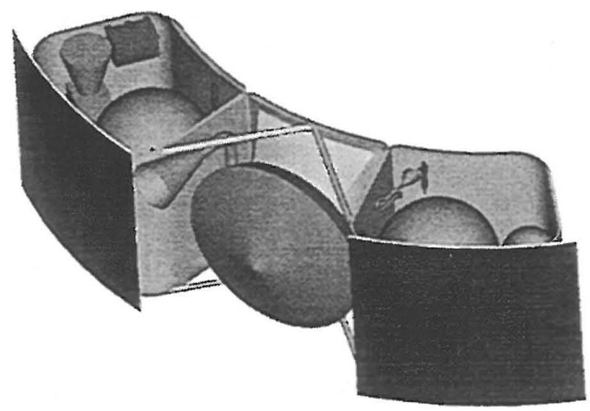
Science-Enabling MicroSpacecraft Constellations for Mars. A. Mauritz[1] and B. Patel[2], [1]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, mauritz.ann@orbital.com, [2]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, patel.bhavesh@orbital.com

By leveraging commercially-developed spacecraft constellation technology, a wide variety of Mars missions can be accomplished ranging from single microspacecraft missions costing less than $50 million to constellations of microspacecraft that provide distributed remote sensing capabilities. Remote sensing missions that require global coverage of Mars can be conducted by constellations of microspacecraft. These microspacecraft provide focused science at low risk. As an additional benefit, these microspacecraft could easily be modified to provide the communication and navigation infrastructure necessary for other complimentary surface science missions.

Orbital Sciences Corporation has extensive experience developing and operating microspacecraft constellations. The figures below illustrate microspacecraft designs applicable to a wide variety of Mars missions. Based on the highly proven Microstar bus, this spacecraft is capable of dedicated or shared launches on a number of launch vehicles including Pegasus, Taurus, Delta II, Delta III, and Ariane 5. Missions enabled by these microspacecraft include constellation-based scientific remote sensing, communications relay, navigation, and distributed aperture sensing. Additionally, this bus can support singular missions focused on probe delivery, remote sensing, or remote monitoring of, and data collection from land-based elements conducting Mars insitu science.

The spacecraft bus utilizes a common set of low mass, low power avionics successfully demonstrated on 38 MicroStar spacecraft currently in operation. By optimizing mechanical designs around specific launch vehicles and payloads, this bus offers a robust means by which to realize many missions. Depending on launch vehicle capability, this bus can support payloads weighing up 70 kg with average payload power requirements in excess of 50W. These proven spacecraft platforms provide an affordable means by which to execute exciting science missions at low risk.





Autonomous Behavior via Multi Parallax Biomimetic Vision Systems. E. D. McCullough

Autonomous behavior based on the simultaneous correlation of multiple visual perspectives with stored data can be used to improve rover performance in difficult terrain on mars, control terminal phases behavior of a planetary descent vehicle and enable autonomous proximity operations near satellites and the Space Station. The stored data is obtained via a training process conducted in rugged and hazardous terrain on earth to establish a baseline of geometric situations and imperatives / constraints which bound the vehicles behavioral options on Mars. This approach would also provide the geometric situational awareness required for a biomimetic vehicle for scaling Martian cliffs. This technology updates Scene Mapping Area Correlator (SMAC) and Digital Scene Mapping Area Correlator (Digi-SMAC) technologies with current terabyte memory, photonics, fast processor technology and the vision system of an arachnid. The autonomous behavior is an emergent property of rapid correlation of geometric constraints.

In this approach, multiple images from different viewpoints are tiled into a composite image (for example a 2x4 array) and correlated with a set of stored tiled images in order to find the closest match. All the input images are correlated simultaneously and a match means that the current geometry around the viewpoints matches the geometry of the selected stored image to a greater degree than any of the others. The use of multiple images increases the number of parallaxes from 1 (humans) to 28 (arachnids) etc. Simultaneous correlation makes the information contained in the additional parallaxes available for guiding vehicle behavior. The correlation is simplified as much as possible to reduce processing loads and is biased to account for time of day, azimuth orientation and sun angle. Additional biases take into account vehicle velocity.

Tiled images along with motion control instructions are placed in the memory by the operator during training activities on Earth. The usage of these stored images and associated data will allow the issuance of motion commands to known points and orientations without path definitions. The vehicle moves from one location to another minding the geometry/velocity (situation) constraints contained in memory. The terabyte memory is necessary to store the required images and data for all the situations in the training program. This training program will also include high speed operation.

Many approaches to terabyte memories are being developed. One of them, the bacteriorhodopsin cube developed by Dr. Robert Birge, can access 200 million memory pages per second. The low access times of these devices combined with the speed of current processors allows the system to go through a full range of constraints to identify hazardous or unsafe geometric/dynamic situations and to modify vehicle velocity and goals accordingly.

As an example, consider a rover with an arachnid vision system.

The rover has 2 eyes mounted on the upper rear corners of the vehicle, 2 mounted high on the front facing forward, 2 mounted on the front of the vehicle facing forward upwards and 2 mounted on the upper front corners of the vehicle facing forward and sideways. All of the eyes view > 2 Pi steradians except for the 2 mounted high and forward which are telescopic and view much less than 1 steradian. The images are detected at each viewpoint with separate CCDs or passively spectrally encoded and sent through fibers to a passive decoder and detected with a single CCD. The acquired images are combined into one tilled image which is compared with similarly tiled images in the terabyte memory data base until the closest match is found. Additional data stored in association with the retrieved image is used to define what the vehicle's behavioral options.

The techniques used in this example could enable many autonomous tasks such as autolanding of Mars descent vehicles, autolanding of helicopters, controlling a set of autonomous vehicles flying in formation with a human piloted aircraft. The technique can be modified to accomplish auto surgery (for example auto removal of thyroid glands in animal carcasses,) auto assembly, auto recognition of fossils, expert control of vehicle subsystems (IVHM,) and interpretation of histograms and spectral data.

MARS METEOR SURVEY. R. D. McGown, B. E. Walden, T. L. Billings, C. L. York, A. G. Taylor, and R. D. Frederick[1],
[1]Mars Instrument and Science Team (MIST), Oregon L5 Society, Inc., P.O. Box 86, Oregon City, OR 97045, email moonbase@home.com.

Proposal: We propose instruments be included on one or more Mars landers to identify and characterize the meteoroid flux at Mars.

Rationale: Mars orbiting spacecraft and ground operations, both manned and unmanned, are vulner-able to meteoroids. There is pure scientific interest in knowing the frequency, intensity, and radiants of mar-tian meteor showers. Being in a different orbit than Earth and closer to the asteroid belt, Mars has un-known cycles and intensities of meteoroid hazards. Knowledge of these hazards can help us manage risk in future missions, particularly extended and crewed missions.

Instruments: To be most effective the detectors should be continuously active, day and night, for as long a period as possible. Detectors that rely on en-ergy-intensive transmitters, such as lasers, radio bounce or radar [1], are therefore less desirable. A staring instrument is preferable to one which must rapidly skew to track a meteor (requiring extra me-chanical parts and susceptible to failure), and should be able to detect multiple meteors simultaneously.

Power Supply In order to obtain representative samples and reliable long-term statistics, a power sup-ply that can maintain function during the martian night and over the martian winter is highly desirable. Ideally the power supply should provide several years of service.

Camera A staring full-sky camera can detect me-teors directly, at least at night (meteor being the flash of light in the atmosphere caused by an infalling mete-oroid). It may be possible to detect them in daylight as well, perhaps using an infrared (IR) camera. Ultra-wide angle 180° lenses are expensive and bulky. A small camera staring down at a lightweight spherical mirror can cover the sky just as well and may be better for dust management. The optics need not be of astro-nomical quality to gather this statistical data, and the small portions of the sky obscured by the camera and its support are relatively insignificant.

Spectrograph Spectrographic capability would give us information about the elemental compositions of Mars' upper atmosphere and the vaporizing meteor-oids. Radial velocity can be determined by doppler shift and combined with transverse velocity to yield a true vector solution for the meteor.

Radio The ionization created by meteoroid entry generates a radio-frequency (RF) signal. It may be possible to detect this emission and derive certain in-formation from it. A radio (or microwave) detector can work day or night. It may also be able to detect smaller magnitude events than an optical/IR detector. In order to localize the signal, at least three receivers and an-tennas are required. It may be possible to integrate the antennas as part of a splayed landing gear array. An-other possibility is to make the optical camera support legs into antennas.

Microphone If a microphone is included as part of another package, some larger, closer meteoroids could produce a sonic boom or other detectable sound. Being able to associate the sound with a detected meteor would help us characterize the nature of sound trans-mission and attenuation through the martian atmos-phere.

Barometer If a barometer is included as part of a martian weather package, it might also record the sonic boom sometimes associated with meteors.

Seismometer If a seismometer is included in a geology package, on this or other landers, coincidence of a seismic signal with a meteor detection could be a confirmation of impact. Further analysis of the seismic signal could help calibrate the meteor detector.

Computer An onboard computer can process the raw data so only a small set of data, consisting of basic meteor identifying parameters, need be included in periodic uploads to Earth. For diagnostic and other scientific purposes, it should be possible to bypass the computer and send broadband raw data to Earth.

Questions: Here are some questions the Mars Meteor Survey might address:

When are martian meteor showers, how big are they, and where do they come from?

Which meteors come from the asteroid belt and which from comets?

Will Mars surface operations be exposed to periodic "rains of rock"? (Fig. 1)

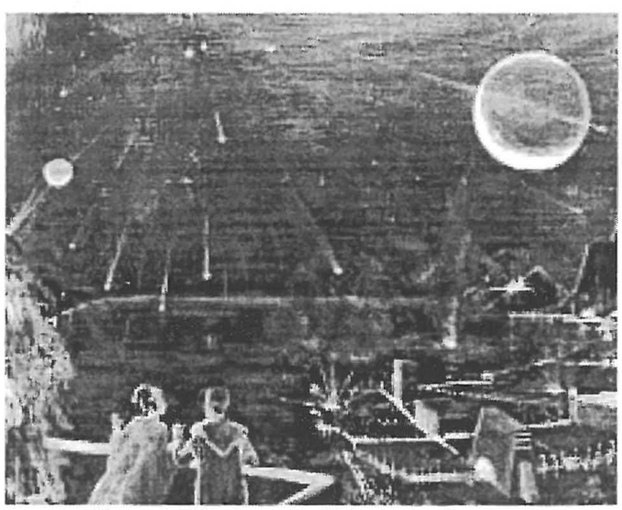


Figure 1. What hazards will future Martians face?

Can we predict meteor showers and storms on Mars?

What is the cumulative risk to surface and orbital operations at Mars due to meteoroids?

How small can a meteoroid be and still reach the surface of Mars?

Are meteorite falls on Mars different in characteristics or time frames from those on Earth?

Would radio or microwave receivers on Mars be sufficient to detect meteors without a reference trans-mitter?

What will meteors look like on Mars? Will they have statistically different characteristics than those seen on Earth?

Are there dust zones or gradients in Mars' atmosphere?

Can wind-shear zones or jet streams in Mars' atmosphere effect meteor signals? [2]

How much of atmospheric dust on Mars is endo-genic (kicked up from the surface) and how much exo-genic (meteoroid)?

Is there a synergy between radio and visible/IR or spectrographic sensors to characterize mass, composition, or other factors of meteoroids or of the martian atmosphere?

Are there statistical differences in composition of Mars meteoroids vs. Earth meteoroids?

Can the Mars Meteor Survey instruments be used in other studies, such as dust storm analysis, imaging during the landing sequence, etc.?

Does Mars have additional small moons?

Further Work: Research existing knowledge from Pathfinder and other missions to better under-stand the martian atmosphere. Find examples of re-corded martian meteors, in order to establish parame-ters for Mars Meteor Survey instruments. Research Earth-based "staring" experiments to identify detection techniques, analysis algorithms, and possible problem areas. Predict possible times for Mars meteor showers based on known Mars-crossing comets, and compare these predictions to actual results. Cooperate with other researchers and planners to create a specific pro-posal for flight. Identify sources and acquire funding to build and fly the Mars Meteor Survey instruments and analyze their data. Publish and disseminate results of the experiment.

References: [1] International Meteor Organization website http://www.imo.net/. [2] Barnes, J. (2000) Personal communication.

Assistance Sought: The Oregon L5 Mars Instru-ment and Science Team would like to work with other professionals in the field to produce the Mars Meteor Survey. Please contact chairman Gus Frederick, gus@norwebster.com, (503) 873-6216 or write to the address above.

Mars Immunoassay Life Detection Instrument (MILDI)

David McKay[1], Andrew Steele[2], Carlton Allen[3], Kathie Thomas-Keprta[3], Mary Schweitzer[4], John Priscu[4], Joe Sears[4], Recep Avci[4], and Keith Firman[2]. [1]Mail Code SN, NASA JSC, Houston TX 77058; [2]University of Portsmouth, Portsmouth, UK; [3]Lockheed Martin Space Operations, Houston TX; [4]Department of Biological Sciences, Montana State University, Bozeman, MT.

The direct detection of organic biomarkers for living or fossil microbes on Mars by an insitu instrument is a worthy goal for future lander missions. We have proposed an instrument based on immunological reactions to specific antibodies to cause activation of fluorescent stains. Antibodies are raised or acquired to a variety of general and specific substances that might be in Mars soil. These antibodies are then combined with various fluorescent stains and applied to small numbered spots on a small (2-3cm) test plate where they become firmly attached after drying. On Mars, a sample of soil from a trench or drill core is extracted with water and/or an organic solvent that is then applied to the test plate. Any substance, which has an antibody on the test plate, will react with its antibody and activate its fluorescent stain. A small UV light source will illuminate the test plate, which is observed with a small CCD camera. The numbered spots that fluoresce indicate the presence of the tested-for substance, and the intensity indicates relative amounts. The entire instrument can be quite small and light, on the order of 10 cm in each dimension. A possible choice for light source may be small UV lasers at several wavelengths. Up to 1000 different sample spots can be placed on a plate 3 cm on a side, but a more practical number might be 100. Each antibody can have a redundant position for independent verification of reaction. Some of the wells or spots can contain simply standard fluorescent stains used to detect live cells, dead cells, DNA, etc. These the stains in these spots may be directly activated; no antibodies are necessary.

The system can look for three classes of biomarkers: those from extant life such as DNA, those from extinct life such as hopanes, and those from organic compounds not necessarily associated with life such as PAHs. Both monoclonal and polyclonal antibodies can used. Monoclonal antibodies react with a very specific compound, but polyclonal antibodies may react to any of a whole family of compounds. Consequently, we do not have to guess which specific compounds may be present on Mars, only which broad families of compounds. Using both kinds increases the chances for hits.

Examples of potential biomarkers for which antibodies may be produced:

1. DNA, RNA and individual bases nucleotides including novel nucleotides used by the archaebacteria.
2. ATP and ATP reductase.
3. Cyclic adenosine monophospate.
4. Hopanes and other steroid-based membrane components which are known to survive for up to 2.5 billion years on Earth as specific biomarkers.
5. Lipopolysaccharides, probably of a cross section of species.
6. General Exopolymeric substances.
7. Porphyrins, including cytochromes, chlorophyll a, bacteriochlorophyll and the Ni and VO replaced porphyrin biomarkers found in oils.
8. 8.Teichoic acids.
9. Specific amino acid or peptide sequences.
10. Flavin adenine dinucleotide (FAD) and nicotinamide adenine dinucleotide (NAD).
11. Antarctic cryptoendolithic biomarkers, specifically the specialized cryoprotectants and UV protectants such as Scytanemin
12. RUBISCO
13. Hydrogenase.
14. Nitrate reductase.
15. Specific PAHs

This list is not exhaustive but serves to illustrate the possibilities. Not only would such a test be able to indicate if traces of viable or non-viable life are present, if that life were viable, this list would enable biologists to determine what its composition was and even something about the metabolism of the organisms.

One aspect of this proposed experiment is that it must be extensively tested on a variety of terrestrial materials including soils to determine its detection limits, its propensity for false positives, and its ability to discriminate among related compounds. Work is currently underway to choose and evaluate a set of reasonable antibodies. Extensive laboratory testing of the antibodies must be done. The mechanical design of the instrument is also beginning. A major objective is to keep the instrument small and simple.

An important feature of the instrument is its potential for multiple missions. Based on the results of the first mission, the mix of antibodies can be modified, and the instrument can be flown again tailored to zero in some additional likely compounds.

PLANETARY MICROBIAL ECOLOGY ON MARS: ENVIRONMENTAL BIOPHYSICS OF MARTIAN MICROENVIRONMENTS. A. Méndez, Department of Physics and Chemistry, University of Puerto Rico at Arecibo (a_mendez@cuta.upr.clu.edu)

Introduction: Earth's planetary habitable zone, the biosphere, includes parts of the atmosphere, hydrosphere and lithosphere (see figure) [1]. Microbial life thrives within this region due to the availability of liquid water, an energy source, nutrients and the right environment. The field of microbial ecology studies the interactions of microbial life with the environment. There are many models and techniques within this field that can be extrapolated to understand the possibilities and limitations of microbial life on Mars past or present environments. The objective of this work is to demonstrate the importance of microbial ecology research on future Mars exploration. The biological relevance of the physical microenvironment characterization of Mars is presented.

Physical Requirements of Life: The environment temperature, pressure, heat transfer (i.e. convection due to wind) and water content are some of the basic physical quantities that affects the microbial physiology. In particular, temperature and pressure are very important as they control the reaction and diffusion rates of the cell's biochemicals. Although much has been studied about the effects of temperature on microorganisms, little is known about the combined effects of pressures and temperatures on microbial growth. Most known microorganisms require an environment temperature for optimum growth of 310 K at standard atmospheric pressure (1.013 bars), but microbial growth is possible between 253 K and 386 K [2,3]. About 85% of the cultured prokaryotes have optimum growth temperatures between 295 and 315 K [4]. This range is outside Earth's average surface temperature (288 K) but it is consistent with the average surface and subsurface temperatures of the equatorial regions on Earth [5].

Steady hydrostatic pressure changes have little or no effect on the growth and metabolism of most microorganisms. Growth of most terrestrial microorganisms is retarded between 300 and 400 bars at 303 K. At 600 bars most terrestrial microorganisms are sterilized, only a few species of marine bacteria grow at such pressure or higher at temperatures between 303 and 313 K [6]. In general, lower temperatures accentuated the growth retarding and sterilizing effects of pressure. Some deep-sea obligately barophilic bacteria are not able to grow at pressures of less than 500 bars, but are able to grow well at higher pressures, even at 1000 bars [7].

There has been little interest about microbial growth at temperatures and pressures similar to the Mars environment. This may be due to the remote or lack of natural Earth's environments with similar conditions (i.e. high altitude mountains). For example, it will be very interesting to determinate if the current martian near-surface environment, protected from UV radiation, provides the necessary physical environment for microbial growth, assuming the other requirements for life are present (i.e. temporal availability of water).

Mars Microenvironment: A microenvironment usually is extremely variable over short space and time scales, but its characterization is necessary when considering organisms mass and energy exchanges. Traditionally, the field of environmental biophysics studies the energy and mass exchanges between living organisms and their environment. In general, it deals with the basic environmental variables: temperature, humidity, wind and radiation. An energy budget equation is used to describe the fitness of the physical environment for life (i.e. microbial growth) given these variables [8].

Characterization of the Mars near-surface microenvironment for biophysical applications will require at least three vertical measurements of temperature, wind velocity, and water content in the atmosphere, and temperature and water content in the soil. Measurements at one location of atmospheric pressure and irradiance will be necessary. This measurements are required as function of time for various sols or seasons to quantify biophysical relevant parameters such as the thermal diffusivity, heat capacity and thermal conductivity of the martian soil. This data can be used to estimate, from the energy budget equation, the minimum energy requirements for microbial growth in the martian surface layer protected from UV radiation and other hazards (i.e. oxidants). This has implications in planetary protection issues about forward and backward contamination risks between Earth and Mars.

Discussion: The characterization of some of Mars' near-surface microenvironments will have more applications besides surface layer physics. They will provide the tools to understand possible biological processes in the Mars' environment. In general, research in this field will:

1. Provide biophysical relevant data to calculate mass and energy transfers between the Mars' environment and microbial life. This will be useful to esti-

mate the potential habitability of Mars by exogenous or indigenous microorganisms.

2. Stimulate and improve theoretical and laboratory simulations about microbial life and possible ecological interactions on the Mars environment.
3. Expand the traditional microbial ecology field, here named "planetary microbial ecology." This field will study the interactions of life with planetary environments including Earth. It is an invitation to microbial ecology scientists to extrapolate their models and techniques to planetary environments such as Mars.

This work only discussed those environmental biophysics relevant considerations for future Mars exploration. They represent the basic physical understanding necessary for geochemical and biochemical studies about planetary microbial ecology on Mars.

References: [1] Méndez A. (2000) *First Astrobiology Science Conference*, 182 (abstract). [2] Friedmann E. I., McKay C. P., Rivkina E. M. and Gilichinsky D. A. (2000) *First Astrobiology Science Conference*, 397 (abstract). [3] Blochl E. R. et al. (1997) *Extremophiles* **1**:14-21. [4] Méndez A., (2000) unpublished data. [5] Méndez A., (1999) *Fifth International Conference on Mar*. LPI **972**:6197 (CD-ROM). [6] ZoBell E. and Johnson F. H. (1949) *J. of Bacteriol.* **57**:179-189. [7] Kato C. et al. (1998) *Appl. and Environm. Microbiol.* **64**:1510-1513. [8] Campbell G. S. and Norman J. M. (1998) *An Introduction to Environmental Biophysics*, 2nd Ed., Springer, 1-13.

Acknowledgements: This work was supported by a research grant from the University of Puerto Rico at Arecibo.

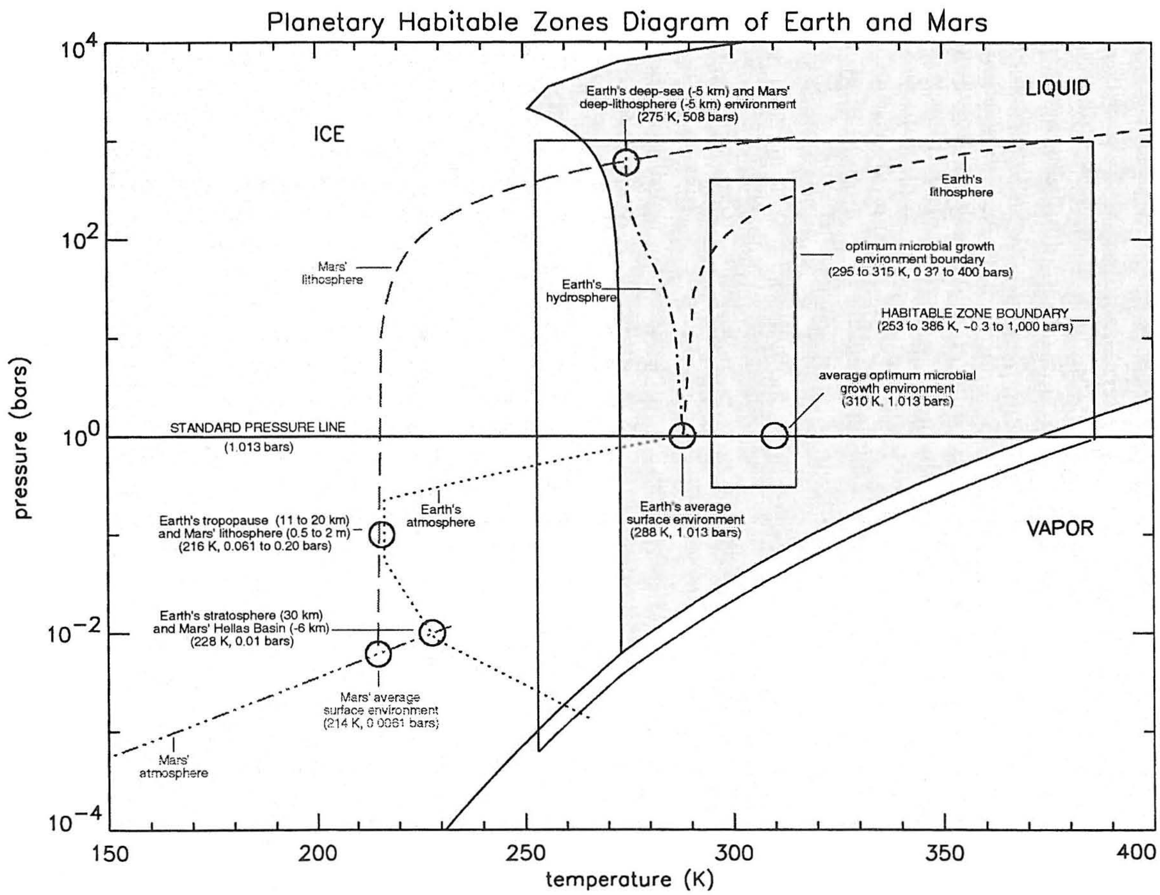


Figure: The Planetary Habitable Zones (PHZ) diagram shows the global-mean steady-state vertical environment physical state of Earth and Mars. In general, the habitable zone boundary delimitates the environment physical state where microbial growth is possible. Outside of this boundary microorganisms are either sterilized or preserved in a dormant state. Growth is also restricted within this boundary due to other factors like the availability of water, an energy source, nutrients, and the particular microbial physiology [1, 5].

Robotic Arms: A Critical Element of any Mars Landed Mission. J. A. Middleton[1], C. S. Sallaberger[2] and T. J. Reedman[3], [1]Vice-President, Strategic Development, MD Space and Advanced Robotics, 9445 Airport Road, Brampton, Ontario, Canada L6S 4J3, jmiddlet@mdrobotics.ca, [2],Director, Space Exploration, MD Space and Advanced Robotics, 9445 Airport Road, Brampton, Ontario, Canada L6S 4J3, csallabe@mdrobotics.ca, [3]Chief Engineer, Advanced Systems Group, MD Space and Advanced Robotics, 9445 Airport Road, Brampton, Ontario, Canada L6S 4J3, treedman@mdrobotics.ca.

Introduction: Landed exploration of Mars requires robust robotic systems capable of satisfying the demands of multiple scientific users. Whether the landed system is a stationary lander or a mobile rover, a robotic arm is an essential element of an exploration system that satisfies scientific needs while providing a method of dealing with unexpected contingencies.

The basic purpose of any landed system is to explore and examine the surface and sub-surface of the planet in question, perhaps in conjunction with technology demonstration elements. To this end the basic needs for exploration are the deployment and retrieval of experiments to and from the surface, the acquisition of surface and sub-surface samples for analysis, and the imaging of the local environment.

A robotic arm satisfies these requirements in a resource efficient manner and also adds an element of robustness to the system.

Mission Architecture: A typical landed exploration system has as its central element a science platform (either static or mobile) capable of supporting a wide range of scientific payloads to examine and determine the state of the planet's surface. The highest level needs for such a system are to:

1. Deploy experiments and instruments of varying sizes to the planet's surface
2. Acquire surface and sub-surface samples and provide them to science instruments for local analysis.
3. Acquire surface and sub-surface samples and transfer to the sample return vehicle (for sample return missions)
4. Provide imagery of the local terrain

An overarching requirement not listed above is the need for a robust system that minimizes the risk of mission failure.

Capabilities. These system needs can be synthesized into the following necessary system capabilities:

1. Handling of multiple payloads varying in size from soil samples on the order of many grams to a rover on the order of many kilograms.
2. Provision of power and data connections to payloads.
3. Dexterity in payload handling to ensure accurate placement and orientation of payloads on either the science deck or the planet surface.
4. Force application sufficient to react both digging and drilling loads
5. Camera support to allow varied imaging of the local workspace.

Generic System Architecture: A robotic arm can used as the basis for a generic system architecture that effectively provides these capabilities, for missions ranging in size from the Mars Surveyor class landed systems to small Beagle II type landers.

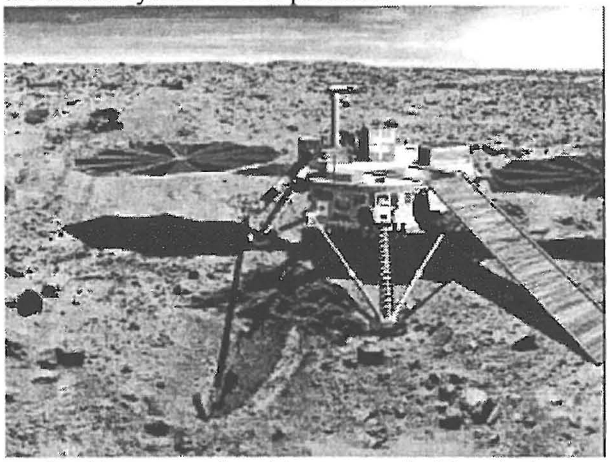
Such a robotic arm would require between 4 and 6 degrees of freedom depending on the specific mission needs. Mass, power and load capacity would be commensurate with the landed system size. The end effector would be capable of handling and servicing many different payloads, varying from digging tools to science instruments. To deal with the limited communications available, the system would be semi-autonomous and capable of some self-diagnosis.

An Illustrative Application: This approach was recently the subject of a feasibility study conducted by MD Robotics, where a systems engineering approach to the mission architecture derived a robotic arm as a solution to the needs of the Mars Sample Return Missions.

System Description. The robotic arm was a 4 degree of freedom pitch plane manipulator with a mass of 7 kg including processing electronics. Power consumed varied between 10 and 20 watts depending on the operating mode and the task being performed. The manipulator had a maximum reach of 2.8m allowing a 2.2m radius surface work area. The manipulator tip was equipped with a multi-purpose end effector capable of handling payloads ranging from an 8 kg sampling drill to rover samples. In order to avoid duplication of existing lander functionality, for the Mars 2003 mission a camera was not included in the arm manifest; however, structural and electrical scarring for a camera was provided.

The tasks envisioned for the arm included experiment deployment and sample acquisition and transfer.

The needs of the scientific community were met through the use of a multi-purpose end effector that allowed the handling of diverse payloads. Power and data lines routed along the arm were connected to the current payload via an umbilical mechanism to allow experiment operation, control and data acquisition by the landed system central processor.



In this proposed architecture, valuable mission robustness was achieved simply by having a flexible, reconfigurable robot in-situ. Should a problem have arisen in the deployment of another lander system the robot arm could be used to investigate the anomaly, providing the earthbound system operators with insight into the situation. If force were required to assist in deployment of a stuck system such as an antenna, the arm could have provided the required impetus.

Risk Management: The utility of a robotic arm in managing mission risk is perhaps best illustrated by considering its potential application in the original Mars sample return missions. The Athena rover was seen as the primary sample retrieval chain. It was deployed by driving down ramps extended from the Lander deck and had to re-ascend the ramps to transfer its samples to the ascent vehicle. The secondary sample retrieval chain was a coring drill, deployed using a simple positioning mechanism.

Using a robotic arm on this mission to deploy the coring drill for its sample acquisition activities created some useful risk management possibilities. For instance, while the arm's primary task was to support the secondary sample retrieval by deploying the coring drill, it could also be used to backstop the primary sample retrieval chain. If the rover ramps became stuck during deployment, the arm could be used to apply assistive force. If the rover required assistance during deployment, the arm could once again apply assistive force. If the rover had difficulty ascending the ramps to transfer its sample to the ascent vehicle, the arm could be used to acquire the samples from the rover on the planet's surface and then deposit them in the ascent vehicle.

In this example application, the robotic arm effectively mitigates mission risk while providing basic functionality for the core mission objective, namely sample retrieval. Other possible contingency activities include assisting in antenna deployment and the cleaning of dust covered optical surfaces such as solar arrays.

Conclusions: A robotic arm should be part of the infrastructure of any multi-purpose landed Mars mission as a method of efficiently deploying and supporting instruments, performing sample collection and sample distribution, while also significantly enhancing mission robustness through its capabilities for contingency operations.

THE SEARCH FOR WATER AND OTHER VOLATILES IN MARTIAN SURFACE MATERIALS: THE THERMAL EVOLVED GAS ANALYZER (TEGA). D. W. Ming[1], W. V. Boynton[2], D. S. Musselwhite[2], S. H. Bailey[2], R. C. Bode[2], G. Quadlander[2], K. E. Kerry[2], M. G. Ward[2], R. D. Lorenz[2], A. V. Pathare[3], D. A. Kring[2], H. V. Lauer, Jr.[1], D. C. Golden[1], I-C. Lin[1], and R. V. Morris[1]; [1]NASA Johnson Space Center, Houston, Texas 77058 (douglas.w.ming1@jsc.nasa.gov), [2]University of Arizona, Tucson, Arizona 85721, and [3]University of California, Los Angeles, California 90024.

Introduction: Volatile-bearing minerals and phases (e.g., Fe-oxyhydroxides, phyllosilicates, carbonates, sulfates, palagonites, glasses) may be important components of the Martian regolith. However, essentially no information exists on the mineralogical composition of volatile-bearing phases in the regolith. The Thermal Evolved Gas Analyzer (TEGA), which was part of the Mars Polar Lander payload, was to determine the abundances of two of the most important volatile compounds (i.e., water and carbon dioxide) in the martian soil and to identify the minerals or phases that harbor these volatiles. The TEGA instrument was composed of a differential scanning calorimeter (DSC) interfaced with evolved gas analysis (EGA) [1,2]. The EGA consisted of a Herriott cell of a tunable-diode laser (TDL) spectrometer that determines CO_2 and H_2O abundances. The sample chamber was to operate at about 100 mbar (~76 torr) with a N_2 carrier gas flow of 0.4 sccm. Specifications of TEGA are described in detail elsewhere in this volume [2].

TEGA Calibrations: Prior to landing on Mars, the TEGA science and engineering team performed numerous calibrations using a TEGA Engineering Qualification Model (TEGA-EQM) located on the University of Arizona's campus. A TEGA laboratory test bed was also developed at NASA Johnson Space Center (JSC) in order to compile a mineral database for the thermal behavior of volatile-bearing phases under reduced pressures appropriate for the flight TEGA. The JSC test bed consisted of a laboratory DSC integrated with a quadrupole mass spectrometer (QMS).

A wide variety of volatile-bearing phases were analyzed by the JSC laboratory test bed, including Fe-oxides/oxyhydroxides/sulfides, phyllosilicates, sulfates, carbonates, palagonites, oxides/peroxides, and zeolites [2]. Reduced pressure operating conditions in the DSC significantly changed the thermal behavior of most volatile-bearing phases as compared to ambient pressure (1000 mbar N_2) operating conditions. In most cases, the onset temperatures for a volatile-release event decreased under reduced pressure operating conditions (e.g., [3,4,5,6]).

The mineral database for thermal responses under reduced pressure operating conditions was used to characterize geological unknown samples that were run on the TEGA-EQM. Here we briefly describe one of those unknown runs that was used for the TEGA Mission Operation Readiness Test (MORT) [7]. R. V. Morris provided the unknown geologic sample to the TEGA team.

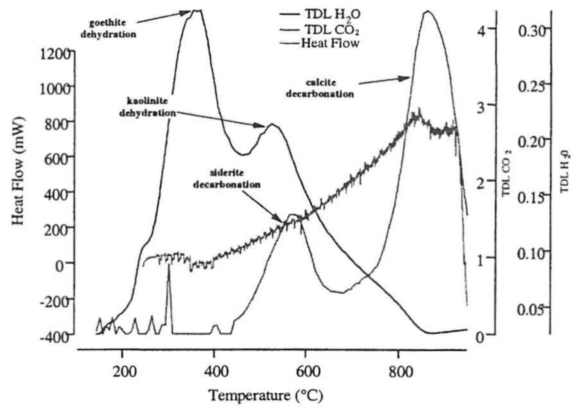


Figure 1. *DSC and evolved CO_2 and H_2O from geologic unknown as determined by TEGA-EQM.*

The unknown geologic sample was first run on the TEGA-EQM. Operating procedures for the run were analogous to the operating procedures planned for the first experiment on Mars. The TEGA-EQM run is shown in Figure 1. From the EGA data, it is clear that there were two major water releases and two decarbonation events. The second decarbonation peak with an onset temperature around 780°C was also clearly evident in DSC as an endothermic response. Based upon the DSC and EGA signatures obtained during the TEGA-EQM run, we used our mineral database to derive a "first guess" sample. The "first guess" sample was composed of siderite, calcite, poorly-crystalline kaolinite, and goethite (Table 1). We ran the "first guess" sample on the JSC laboratory test bed. Although the DSC and EGA signatures were similar to those of the geologic unknown sample, the low-temperature water release for the "first guess" sample did not fit the water release in the unknown run. We added an unaltered tephra from the Puu Huluhulu cinder cone in Hawaii and slightly changed the proportions of the other minerals to come up with a "best-guess" sample (Table 1). The DSC/EGA curves for the "best guess" sample derived from the TEGA-EQM are shown in Figure 2. The EGA of the "best guess" sample was very similar to the TDL signatures for the unknown sample. Once the TEGA team submitted the "best guess" sample as a possible candidate for the geologic unknown, the team was informed of its chemical and mineralogical properties. The unknown was British Chemical Standard, Lincolnshire iron ore (BCS No. 301/1), which consisted of siderite, calcite, poorly-crystalline goethite, and quartz. Interestingly, the TEGA team suggested that the geologic unknown also contained a 1:1 phyllosilicate (e.g., kaolinite) based upon the dehydration event that begins around 470°C. After detailed mineralogical analysis of the unknown sample (X-ray diffraction analysis of clay-sized fraction), a 1:1 phyllosilicate (probably kaolinite) was detected (XRD peak at 0.7 nm), which apparently was not identified when the chemical standard was originally characterized.

The EGA signatures are quite similar between the unknown and best guess samples (Table 2). The two dehydration events are assigned to the dehydroxylation of goethite and kaolinite with onset temperatures around 200-210°C and 470°C, respectively. The two decarbonation peaks with onset temperatures near 450-480°C and 685-705°C were assigned to siderite and calcite, respectively. The DSC signatures for the unknown and best guess sample have quite different shapes; however, the endothermic response to the decarbonation of calcite is evident in the DSC with an onset temperature just above 700°C.

TEGA and Future Mars Missions: These tests illustrate the outstanding capabilities that a TEGA-like instrument will have on Mars surface missions for detecting and identifying volatile-bearing phases. The TEGA TDL is very sensitive and can detect H_2O amounts down to 10 ppm and CO_2 down to the equivalent abundances of 0.03 %. Therefore, TEGA is uniquely qualified to search for water and CO_2 reservoirs on Mars. Suggested improvements to TEGA for future Mars missions are provided elsewhere in this volume [2].

We anticipate that TEGA or TEGA-like instruments will be instrumental in fulfilling NASA's Space Science Enterprise strategy for Mars of "following the water" as part of a "quest for life." TEGA-like instruments will be needed to determine the abundances of water and other volatiles in the Martian regolith to support long-term human presence on the surface.

References: [1] Boynton, W. V. *et al.* (2000) *J. Geophys. Res., in press.* [2] Boynton, W. V. *et al.* (2000) In *Concepts and Approaches for Mars Exploration,* LPI, Houston, TX, *This Volume.* [3] Lauer, Jr., H. V *et al.* (2000a) In *Lunar & Planet. Sci. XXXI,* Abst. # **1990**, LPI, Houston, TX (CD-ROM). [4] Lauer, Jr., H. V. *et al.* (2000b) In *Lunar & Planet. Sci. XXXI,* Abst. # **2102**, LPI, Houston, TX (CD-ROM). [5] Golden, D. C. *et al.* (1999) In *Lunar & Planet. Sci. XXX,* Abs. # **2027**, LPI, Houston, TX (CD-ROM). [6] Lin, I-C. *et al.* (2000) In *Lunar & Planet. Sci. XXXI,* Abst. # **1417**, LPI, Houston, TX (CD-ROM). [7] Musselwhite, D. S. *et al.* (2000) In *Lunar & Planet. Sci. XXXI,* Abst. # **2044**, LPI, Houston, TX (CD-ROM).

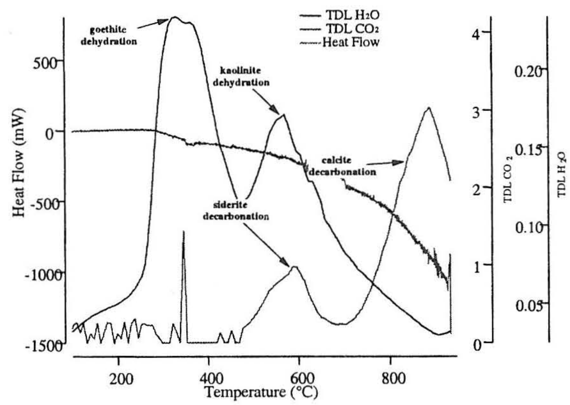


Figure 2. *DSC and EGA for "Best Guess" sample determined by TEGA-EQM.*

Table 1. *Mineral composition of "unknown" and "best guess" samples.*

Geologic Unknown mineral	wt. %	First Guess Sample mineral	wt. %	Best Guess Sample mineral	wt. %
siderite	12.1	siderite	10	siderite	8
calcite	44.1	calcite	47	calcite	38
1:1 clay	12.5	kaolinite	8	kaolinite	6
goethite	29.1	goethite	35	goethite	28
quartz	2.3			tephra	20

Table 2. *Assignments of temperature features in TDL EGA data for unknown and "best guess" samples.*

Signature	Temperature (°C) Unknown	Best Guess	Assigned Thermal Event
Onset 1st H_2O peak	200	211	goethite dehydroxylation
Onset of 2nd H_2O peak	468	469	kaolinite dehydroxylation
Onset of 1st CO_2 peak	451	480	siderite decomposition
Onset of 2nd CO_2 peak	685	705	calcite decomposition

Measurements of Water Ice from Martian Orbit and on the Surface

Igor G.Mitrofanov[1], Dmitrij S.Anfimov[1], Sergej P.Handorin[1], Andrej A.Kondabarov[1], Maxim L.Litvak[1], Lev B.Pikel'ner[2], Yuri P.Popov[2], Valery N.Shvetsov[2], Alexander V. Strelkov[2] and Alexander K.Tonshev[1],

[1]Institute for Space Research (IKI), Moscow, Russia (imitrofa@space.ru);
[2] Joint Institute for Nuclear Research, Dubna, Russia;

Cosmic rays are known to produce large number of high-energy neutrons at the Martian surface. These neutrons produce gamma-ray lines from the nucleus either via inelastic scattering (I-type lines), in which they keep their original high energy, or via capturing reactions (C-type lines), in which they are slowed down to epithermal or thermal energies These lines together with the lines produced by natural decay of K, Th and U (N-type lines) will be measured by the Gamma-Ray Spectrometer with high purity Ge detector. The mapping of these lines will allow the investigators to determine the distribution of the principal minerals globally over the Martian surface, which is one of the primarily goals of the Mars Surveyor Orbiter 2001 mission.

The main scientific objectives of Russian High Energy Neutron Detector HEND are consistent with this goal. HEND, as a part of GRS facility, will provide the map of high-energy neutron albedo, which will allow (together with the complementary map of low energy neutron albedo from the Neutron Spectrometer NS) to distinguish I-type, C-type and N-type lines among the forest of lines from the GRS spectrometer.

With the increase of hydrogen content in the surface layer, the termalization path of high energy neutrons is shortened, and the ratio between original high energy neutrons and thermal neutrons decreases. The mapping measurements of this water-sensitive signature is the second main objective of the HEND.

To achieve these goals, HEND has three ^{3}He-based counters of neutrons for energy ranges 0.01 – 1.0 eV, 1.0 – 1000.0 eV and 1.0 – 1000.0 keV with thin, medium and thick moderators, receptively. For the highest energy range of 1.0 – 10.0 MeV HEND has one Stilben-based scintillating detector with active anti-coincidence shielding around it. The HEND data on of neutrons at four energy ranges will be accumulated during the mapping stage of the mission. The deficit of high-energy neutrons in respect to increase of thermal neutrons will be considered, as the observational signature of water rich regions at the surface of Mars. If this signatures will be found for some Martian regions, the models of energy spectra of neutrons will allow to estimate the average amount of ice and to build the contours of water surface density over the region area.

However, the special resolution of orbital mapping will be limited by scale of tens or/and hundred of kilometers, or even worse. The features of the Martian surface have much smaller scale of tens and hundreds of meters, and we may assume that water rich regions contains large number of local spots of ice deposits, which are implemented into the basic surface materials.

We believe that comprehensive studies of these local ice spots may be one of goals of future Mars exploration. The first reason is related with science. The separated spots of ice are very interesting places for surface and subsurface exploration. The shape and size of these ice deposits are very interesting for the theory of surface evolution; the chemical and bio-chemical impurities in water may be the subjects of in-situ scientific analysis. Also, the future sample return mission may take into account the possibility to take some samples of ice for returning collection.

The second reason is related with future technological programs. The large spot of ice is the reservoir of water and the resource of oxygen production. Future mission may be developed taking into account the knowledge about the water ice spots on the Mars.

Therefore, we will discuss the concept of future mission to Mars to search and to measure local spots of water ice in the surface and subsurface layer. We will suggest the instruments for measurements of neutrons at the surface, which will be able to detect the local signatures of water. This instruments will be optimized to measure the differences of fluxes of high-energy neutrons and thermal neutrons at the surface. Also, we will compare different options of moving vehicles, which may carry these instruments, may ensure the small scale mapping of water-reach regions, and may perform the ice sample collection, if necessary.

We will discuss the possible scenario of missions for searching and exploration of subsurface ice water:

At the first stage the orbital remote sensing of gamma-ray lines and neutrons albedo will select the surface regions with presence of ice deposits. This stage will be concluded by the map with surface density contours of ice with resolution of tens-hundreds kilometers. Mars Surveyor Orbiter 2001 will perform this stage.

At the next stage some regions may be selected for lending, and the lander may deliver the movable vehicles to this site. The vehicle will measure the map of the area with size of several kilometers and with special resolution of tens of meters. The separate spots of subsurface ice water could be discovered at this stage.

At the third stage the mission with precision landing capability will be decanted nearby to the selected ice spot for in-situ scientific analysis of water and/or for collection of ice sample for future sample return mission.

Finally, at the fourth stage the sample of water ice could be studied in laboratories for fine analysis of possible signatures of organic.

DESIGNING A MARS MISSION THAT WILL GENERATE PUBLIC EXCITEMENT AND SUPPORT: SAMPLE RETURN USING *IN SITU* PROPELLANT PRODUCTION. P. J. Mueller, Space Dynamics Laboratory/Utah State University, 1695 N. Research Park Way, North Logan, UT 84341-1947, paul.mueller@sdl.usu.edu.

Introduction: Publicly funded space missions (e.g.all NASA missions) must be perceived by the public as worthwhile in order to retain broad support for NASA and a sustainable space program. In addition, if the public finds the missions exciting and even entertaining, then the level of support will be even greater. "Good Science" alone is not enough to keep the public interested in space. Examples of missions that generated great public enthusiasm and those which were hardly noticed are given. A Mars sample return mission architecture is proposed which will generate much public interest and also provide solid scientific research.

NASA and Its Customers: Too often, NASA seems to think that the space science community is its main customer. Missions are designed around the "best" scientific experiments based on peer review. While scientific merit is important, it is not the only consideration in designing a mission architecture. The ability of the public to become vicariously involved in the mission is also very important. The ultimate expression of this is sending humans to new, unexplored places, and and providing video downlink to bring the experience into our living rooms.

What Makes Missions Interesting or Boring? As just mentioned, the most interesting missions are those where humans are exploring the unexplored. The obvious cases are the early space flights and the Apollo program, especially Apollo 11. Next are robots which can provide a vicarious exploration experience (once again, video is critically important), such as the Sojourner rover driving around and checking out the area around the Pathfinder landing site on Mars, or Voyager zooming by Jupiter and sending back dramatic pictures. Next on the scale is having humans perform interesting tasks in a more routine environment. Examples include manually grabbing a satellite when the shuttle robot arm was unable to snare it, or installing a sunshade over Skylab's outer surface. Robots performing interesting tasks is next, such as building a "robotic colony" on Mars. Then comes using humans to perform routine tasks, including very important scientific experiments. Many Space Shuttle missions come to mind. And lowest on the "interest" scale is using robots or scientific instruments to gather data of a non-visual nature. A good example of this is the probe dropped by the Galileo orbiter into the atmosphere of Jupiter. No dramatic pictures "looking out the window" were available, so the public showed very little interest. Or imagine the Mars Pathfinder web site if there were no pictures were available. It is hard to imagine millions of web site "hits" to see the latest X-ray spectrometry data from one of the rocks, for example.

What Makes a Mars Sample Return Mission Worthwile and Interesting to the Public? Obviously, the idea of bringing back rocks for analysis is inherently interesting. The possibility of finding signs of life (extant or extinct) is also tantalizing. But the concept of demonstrating technologies to be used in future human missions will also be seen as very worthwhile and interesting. In-situ propellant production (ISPP) is seen as innovative and a good way to reduce mission costs for future human missions. But ISPP will probably be more technically challenging and costly than other approaches for a relatively small-scale sample return mission. So a mission using ISPP will probably be later in the program, after the first samples have been returned. So the thrust of the mission will be to demonstrate technologies needed for upcoming human missions, and to use these technologies to bring a sample back to Earth as a bonus. Unfortunately, such a mission does not lend itself well to using video to provide exciting images. The best way to generate interest is to locate the vehicle with a "robotic colony", so that its power and propellant generating equipment can be used for other tasks once the sample-carrying vehicle has launched on its return to Earth. The video would show the robotic colony building up infrastructure from other missions, to become the base of operations for the first human mission.

THE SEARCH OF CARBONATES IN MARTIAN DUST. L. M. Mukhin, University of Maryland, Department of Physics, College Park MD 20742, USA.

The problem of carbonates budget on Mars still remains as one of the most controversial. Although carbonates of different types are generally believed to be present on Mars surface, there are no successful experiments for their indication. Earth-based spectroscopy gives only upper limit (few %) for calcium carbonate. The Viking experiments were obviously unsuccessful due to low temperature for decomposition of carbonates. Pollak et al. suggested too high concentration of carbonates in airborne dust (1-3%). Meantime the Martian dust should represent the mixture of different minerals formed by wind abrasive. In the first approximation, the mineral composition of the dust should correspond to the average mineral composition of Martian surface. Therefore, the attempt to determine carbonates in samples of the dust from surface looks promising

We propose for future experiments on Martian surface simple, high-sensitive method for determination sorbtion-desorbtion processes of carbon dioxide on the particles of Martian regolith as well as determination of carbonates with level of sensitivity from 10 to 100 ppb. So called method of thermostimulated desorbtion will use the measurement of changing in partial pressure of carbon dioxide during the step heating of the sample. The instrument will consist from dust sampler, pyrolitical cell with temperature range from ambient up to 900-1000C and simple GC. The collection of dust particles should be processed with TV camera control. The total weight of this type of instrument should not be more than 500g.

PHOBOS, DEIMOS MISSION. L. Mukhin, R. Sagdeev, K. Karavasili, and A. Zakharov.

One of primary goals of the Solar System Exploration Program is to determine how planets and small bodies evolved. Phobos and Deimos from a technical point of view are more accessible as the targets for space exploration than most of the small bodies. There is a need to understand the basic scientific nature of the Martian moons, both as representatives of the family of Small Bodies in the Solar System and as components of the Mars planet system. There are a number of key unresolved scientific problems related to the Mars, Phobos, and Deimos (MPD) system. The main one being the problem of origin and evolution of the MPD system, solution of which requires knowledge of the chemical composition of Martian moons, impact history and surface morphology, internal structure etc. This investigation fits into the Mars Exploration Program, as the moons are part of the entire Mars system. Study of the fundamental physical and chemical state of Phobos and Deimos will provide information required for understanding the origin and evolution of the Martian planetary system. In spite of previous efforts, their composition, internal structure and details of the processes, which produce their surface morphology, are poorly understood. Because of this, the models of their origins are not well constrained. Missions to Phobos and Deimos with the appropriate instrumentation would be capable of addressing the unresolved issues.

Thus the main scientific goal of a Phobos/Deimos mission is to study the different characteristics of the Martian satellites, and understand their origin and evolution.

The specific choice of potential missions defines the nature of the experiments.

The scenario for a close by approach to Phobos and Deimos requires the ability of orbital maneuvering in the gravity field of Mars. The net ΔV needed to support such maneuvers is somewhat higher than 1 km/sec and almost independent of whether initial insertion orbit is a standard Mars capture one or approaching Mars with a slow relative velocity from heliocentric orbit.

The main technical concept for the spacecraft is based on using existing electric-powered thrusters as the spacecraft propulsion system for forming spacecraft orbits synchronous with Deimos and Phobos. Preliminary estimates show that the use of such thrusters is compatible with creation of a small, low-cost spacecraft of about ~150 kg, which will include science instruments, having a mass of about ~25 kg. The instrument designs critical for such a scenario have already undergone the development phase (some have even flown on different missions), therefore increasing the feasibility of the suggested scenario and further decreasing the cost of an appropriate mission. Possible mission scenarios imply detailed remote sensing of Phobos and Deimos, and possible landing on Phobos. The spacecraft can operate on Deimos-like and Phobos-like circular Mars orbits synchronized with Deimos' and Phobos' orbital motion. The spacecraft during its synchronous orbiting can fly at altitudes of several km over the surface of Phobos and Deimos. The strategy of minimal altitude flights over Deimos and Phobos would require a more detailed knowledge of their gravity fields to secure the safe maneuvering under given electric propulsion and final landing on the surface of Phobos and/or Deimos.

The close by remote sensing of Martian moons (while co-orbiting) can provide global coverage data related to both the surface and internal structure of the satellites:

- global geologic mapping,
- size, shape, mass, bulk density,
- color, albedo, photometric scattering and thermal properties,
- mapping of global elemental and mineral composition,
- magnetic properties,
- internal structure,
- Landing site certification and selection.

Operation of the spacecraft in orbits close to Phobos and Deimos provides also a chance to study the respective dust tori (the Martian rings), to study the peculiarities of their orbital motion and libration, and to study the interaction of small bodies with the solar wind.

Direct measurements on Phobos'/Deimos' surface will provide the opportunity to acquire ground truth data needed for validation and interpretation of remote sensing data and to perform a detailed, in situ study of regolith samples:

- elemental and mineral composition,
- volatile content,
- microscopic structure, physical and mechanical properties of the regolith,
- states of magnetization.

VISIBLE WAVELENGTH SPECTROSCOPY OF FERRIC MINERALS: A KEY TOOL FOR IDENTIFICATION OF ANCIENT MARTIAN AQUEOUS ENVIRONMENTS. S. L. Murchie[1], J. F. Bell, III[2], and R.V. Morris[3], [1]Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 (email: scott.murchie@jhuapl.edu); [2]Department of Astronomy, Cornell University, Ithaca, NY 14853 (email: jimbo@marswatch.tn.cornell..edu); [3]NASA / Johnson Space Center, Houston TX 77058 (email: richard.v.morris1 @jsc.nasa.gov).

Introduction: The mineralogic signatures of past aqueous alteration of a basaltic Martian crust may include iron oxides and oxyhydroxides, zeolites, carbonates, phyllosilicates, and silica. The identities, relative abundances, and crystallinities of the phases formed in a particular environment depend on physicochemical conditions. At one extreme, hot spring environments may be characterized by smectite-chlorite to talc-kaolinite silicate assemblages [e.g., 1,2,3], plus crystalline ferric oxides dominated by hematite. However, most environments, including cold springs, pedogenic layers, and ponded surface water, are expected to deposit iron oxides and oxyhydroxides, carbonates, and smectite-dominated phyllosilicates [4,5,6]. A substantial fraction of the ferric iron is expected to occur in nanophase form, with the exact mineralogy strongly influenced by Eh-pH conditions [e.g., 4,7].

Detection of these phases has been an objective of a large body of terrestrial telescopic, Mars orbital, and landed spectral investigations and *in situ* compositional measurements. However, clear identifications of many of these phases is lacking. Neither carbonate nor silica has been unequivocally detected by any method. Although phyllosilicates may occur near the limit of detection by remote sensing [8], in general they appear to occur in only poorly crystalline form. In contrast, compelling evidence for ferric iron minerals has been gathered by recent telescopic investigations, the Imager for Mars Pathfinder (IMP), and the Thermal Emission Spectrometer (TES) on MGS. These data yield two crucial findings. (a) In the global, high spatial resolution TES data set, highly crystalline ferric iron (as coarse-grained "gray" hematite) has been recognized but with only very limited spatial occurrence. (b) Low-resolution telescopic reflectance spectroscopy, very limited orbital reflectance spectroscopy, and landed multispectral imaging provide strong indications that at least two broad classes of ferric iron minerals are commonplace in non-dust covered regions.

"Gray" Hematite: TES results show that nearly all dark, gray regions of Mars (widely interpreted as minimally altered crustal rock) exhibit thermal emission spectra consistent with basaltic to andesitic compositions [9]. The only exception yet found by TES is Sinus Meridiani, whose thermal emission spectrum shows evidence for hematite with such a coarse particle size (>5-10 μm) that its dark, flat visible to near-infrared (NIR) spectrum lacks the diagnostic features of finer-grained, "red" hematite [10]. Both red and gray hematite occur on Mars; the distinction has important implications for past aqueous and thermal environments [10], and accurately making the distinction requires both visible-NIR and thermal IR measurements.

Ferric Minerals in Dark Gray Regions: Visible-NIR telescopic spectroscopy has shown that some dark gray regions exhibit relatively strong absorptions near 660 and 860 nm [e.g., 11]. These regions indicate a greater concentration of finely crystalline ("red") ferric minerals than in the dust (Fig. 1). One of the highest concentrations is in eastern Syrtis Major (arrow, Fig. 1), which was measured at comparable spatial resolution (~20 km/pixel) by the Phobos-2 ISM instrument. That region's spectral properties and the long-term stability of its albedo and color patterns indicate that the crystalline ferric material likely occurs in a stable form, possibly coating basaltic rock [12].

IMP multispectral images also detect the phase having a strong 660-nm absorption (Fig. 2). Its lack of a strong absorption near 530 nm implies a ferric phase other than hematite, perhaps schwertmannite, akaganeite, or goethite or lepidocrocite in nanophase form [13]. Occurrence of the phase is primarily restricted to dust-coated rocks in IMP data [15]. An excellent terrestrial analog is red desert varnish, in which windblown soil is cemented to rocks by recrystallization of ferric iron in the presence of liquid water [15].

Ferric Minerals in Dark Red Regions: NIR spectra from ISM show that dark red regions are distinctive spectrally from dark gray and bright red regions. They are strongly ferric, with a 0.9-μm band deeper and offset to longer wavelengths than in dust, suggesting a different mineralogy [16]. Analogous materials occur at the Pathfinder landing site [17,18]. Spectrally, in the NIR they are consistent with ISM measurements of dark red soils, but they lack the 660-nm absorption characterizing the phase in the rock coatings. Possible ferric phases in the dark red soil are maghemite and ferrihydrite [13,17,18], although interpretations involving a both a ferrous mineral and nanophase ferric oxide are also possible.

Summary: Visible-NIR spectroscopy has detected two classes of ferric iron spectral signatures distinct from dust. Phases consistent with the data mostly require water for their formation. Unlike coarse-grained hematite, these materials have not yet been detected at thermal wavelengths, possibly due to very fine particle sizes. Thus, a key part of the mineralogic signature of past aqueous environments probably occurs as poorly crystalline ferric minerals. Visible-NIR reflectance spectroscopy is a proven tool for detecting such materials, and is therefore an essential part of an effective strategy for identifying ancient aqueous deposits.

VISIBLE-WAVELENGTH SPECTROSCOPY OF Fe MINERALS: S. L. Murchie, J.F. Bell III, and R.V. Morris

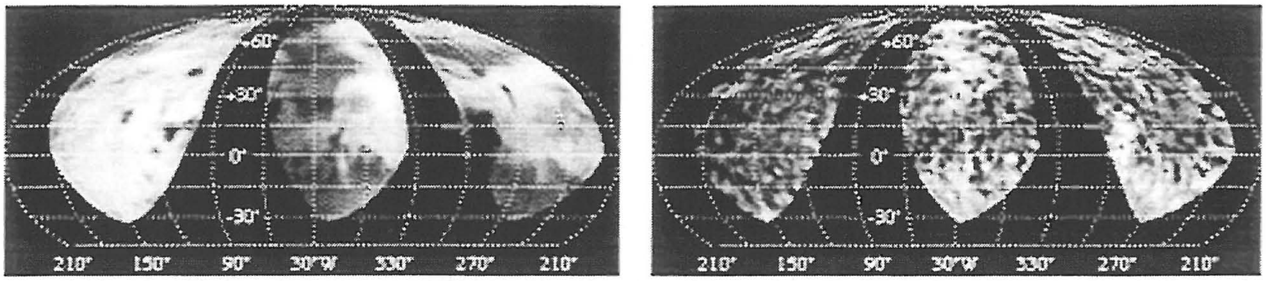


Fig. 1. Map-projected products derived from HST imaging of Mars [9]. Arrow marks eastern Syrtis Major. Left: 673/410 nm ratio. Areas with lesser dust cover appear dark. Right: 860-nm ferric band depth. Stronger bands appear brighter. Note that the strongest bands appear in areas with little dust.

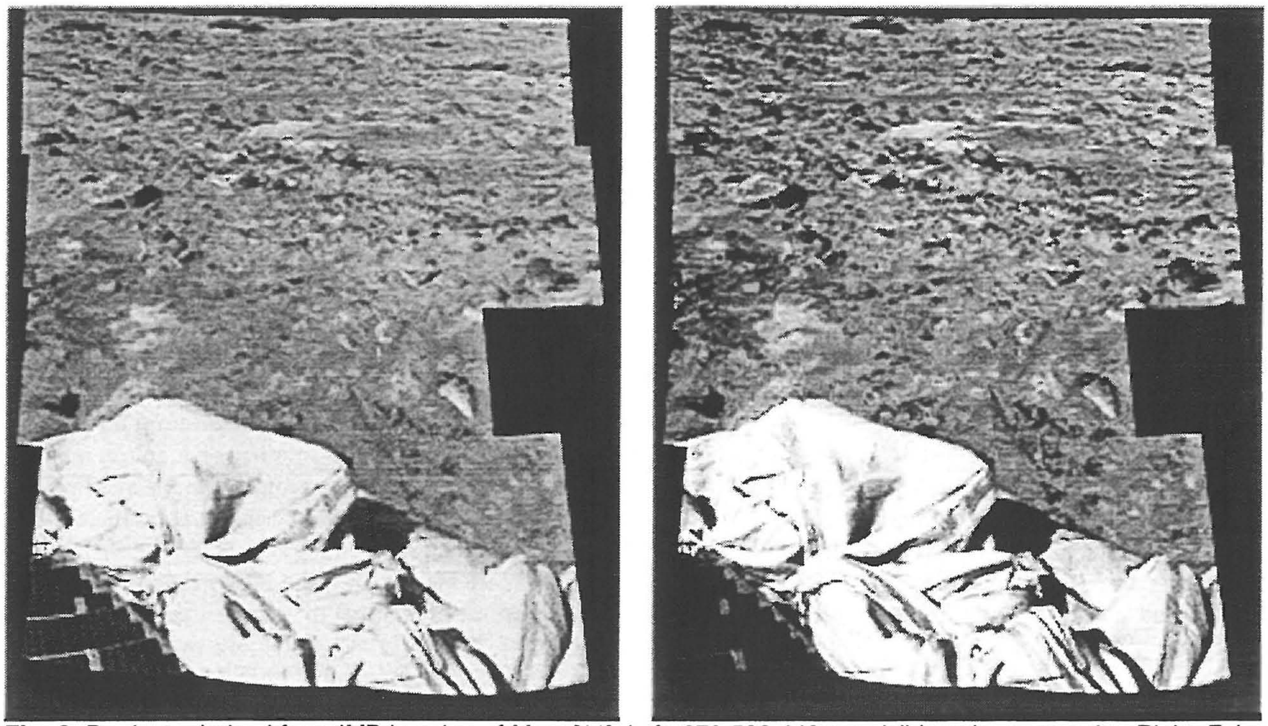


Fig. 2. Products derived from IMP imaging of Mars [11]. Left: 670-530-440 nm visible color composite. Right: False color representation of strength of 660-nm ferric band. Stronger bands appear in redder hues. Not that stronger bands are confined to coated rocks and are absent from dust and soil.

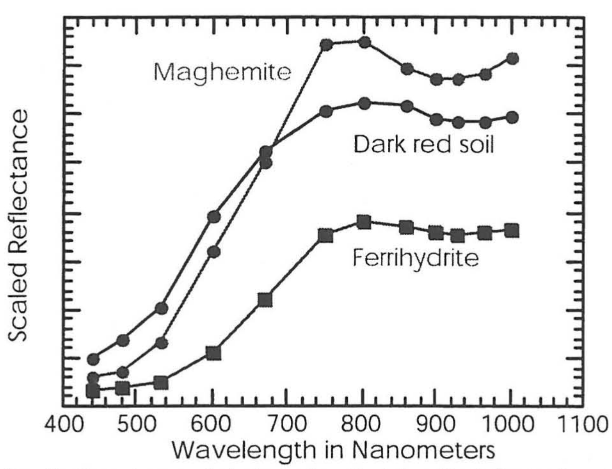


Fig. 3. Spectrum of dark red soil at the Pathfinder landing site compared with the most similar mineral analogs.

References: [1] Kristmannsdóttir H. (1997) *JGR, 87,* 6525-6531. [2] Mehegan J. *et al.* (1982) *JGR, 87,* 6511-6524. [3] Shau Y. and Peacor D. (1992) *Mineral. Petrol., 112,* 119-133. [4] Banfield J. (1991) *GCA, 55,* 2781-2793. [5] Robert C. and Goffé B. (1993) *GCA, 57,* 3597-3512. [6] Cornell R. and Schwertmann U. (1996) *The Iron Oxides: Structure, Properties, Reactions, Occurrences, and Uses,* VHC, New York. [7] Allen C. and Conca J. (1991) *Proc. Lunar Planet. Sci., 21,* 711-717. 6524. [8] Murchie S. *et al.* (1993) *Icarus, 105,* 454-468. [9] Bandfield J. *et al.* (2000) Science, 287, 1626-1630. [10] Christensen J. *et al.* (2000) *JGR, 105,* 9623-9642. [11] Bell J. *et al.* (1997) JGR, 102, 9109-9123. [12] Mustard J. *et al.* (1993) *JGR, 98,* 3387-3400. [13] Morris, R. *et al.* (2000) *JGR, 105,* 1757-1818. [14] Barnouin-Jha O. *et al.* (2000) *Lunar Planet Sci. XXXI,* 1262. [15] Dorn R. (1991) *Amer. Scientist 79,*542-553. [16] Murchie S. *et al.* (2000) *Icarus,* in press. [17] McSween H. *et al.* (1999) JGR, *104,* 8679-8716. [18] Bell J. *et al.* (2000) *JGR, 105,* 1721-1755.

ROBOTIC OUTPOSTS: THE MISSING LINK IN MARS EXPLORATION PLANNING. B. Murray[1] and L. Friedman[2], [1]California Institute of Technology, 1200 E. California Blvd., 150-21, Pasadena, CA 91125, (626) 395-3780, bcm@caltech.edu, [2]The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106, (626) 793-5100, tps.ldf@planetary.org.

The emerging opportunity: Mars Exploration is a long-term endeavor--many presidencies, 15+ Congresses. It needs frequent self-renewing milestones and annually affordable budgets, sustained by a widely shared vision of a human future on Mars. However, there is currently no well-defined transition, which can be visualized, from the planned robotic program to an anticipated, but not yet authorized program, to achieve the first human presence.

The robotic and human programs can be joined physically and geographically through the establishment of one or more Mars Outposts, robotic research sites that become certified and equipped landing sites for subsequent crewed flights. The implementation of such Outposts linking human and robotic exploration would provide major and affordable milestones on the popular road to Mars. It could increase NASA's confidence and innovation in Mars exploration.

Lessons from the past: Apollo provided unique experience with human landing on an alien surface, but may not be the most appropriate analogy overall. Early Antarctic exploration required long sailing voyages and traversing the seasonal pack ice. Endeavors required years, not weeks. Best available technology (such as using arctic sled dogs and ski) was the norm. The IGY and subsequent phases were enabled by air and sea transportation originally surplus from WW2, not by special, expensive development programs. More than half a century transpired from the turn of the century "Race to the South Pole" to the establishment of a continually manned base at the South Pole. This transition was accompanied by an evolution from an early nationalistic, symbolic phase to the current international, science-driven phase.

Applications to Mars exploration: Using Antarctica as a template, Mars exploration could easily comprise much of a century reaching the milestone of first human presence and, like Antarctic exploration, can be expected to ebb and flow with trends and traumas on Earth. WW1 ended the first phase of Antarctic exploration and WW2 enabled the more recent one. Mars exploration efforts should be structured to be adaptable to both unexpected opportunities and to disappointing delays. Gradual buildup of Outposts can provide this flexibility.

The Apollo program developed much new space technology. In contrast, Mars exploration most likely will have to rely to a much larger extent on adapting existing space technology to the special Martian needs. Where unique new technology is essential, such as in-situ propellant production, compact nuclear power sources and long-duration human flight away from Earth, it will have to be developed incrementally, avoiding excessive annual funding requirements and inflexible schedules. High initial cost profiles have been a chief inhibitor to the start of a human Mars program. The Outpost can contribute to this incremental buildup by providing test results and small-scale, lower cost applications in support of robotic exploration long before such special martian systems are used by humans.

A human Mars goal is usually recognized as a benchmark post-Space Station international endeavor. International participation is likely to be necessary for the broad, enduring political support the goal requires. Thus, the Mars Outpost concept should be viewed in an international context from the beginning. By building in a step-wise and small-scale manner, many nations can contribute. The Outpost can be an effective means to build a robust international partnership, one not dependent on single programmatic decisions.

Help from the future - the information technology explosion: In contrast to relatively static human capabilities, the power of human-assisting tools is increasing rapidly, especially those exploiting the information technology revolution. Moore's law applies generally to communications, computing, robotics, input/output, artificial intelligence, visualization, and simulation. We have thousands of times more information technology capability available to support space flight now than during Apollo. We can also expect to have yet hundreds of times more by the time of the first human flights to Mars. Modern society is rushing into an unprecedented interactive and information-rich world. Mars exploration must somehow exploit that environment and capability if it is to be affordable and popular. Information technology somehow must be exploited to make going to Mars much less costly than Apollo was.

We must define carefully the intrinsic role of humans immersed within the complex human/machine symbiosis of the future. What are the unique human capabilities essential for Mars exploration? How can they be enhanced by new information technology?

How can non-essential tasks be handled autonomously? Virtual reality, both locally and globally on Mars, may be especially important. Mobile robotic surveillance and continuous wireless communication between all surface units at an Outpost and elsewhere on Mars may also be important. What is especially important to today's Mars planning, is that developing these capabilities serves the robotic program and the human program equally well.

Basic engineering functions must be evaluated with an eye to miniaturization and to autonomy. The Mars Outpost infrastructure needn't necessarily be "human-scale" in order to prepare for meeting human needs. Miniaturized and autonomous infrastructure needn't wait until the humans arrive to start functioning. Better that such subsystems be developed incrementally, tested and directed to carry out increasing DIFFICULT robotic science tasks in stages. But the early design process requires a vision of the entire exploration process, at least up through human occupancy of one or more Mars Outposts.

Possible scientific attributes of Mars Outposts: The initial, distributed infrastructure of the bases connected by robust wireless communications might include long-lived elements such as: (1) Earth and Mars communication system; (2) high-capacity computing and data storage; (3) navigation and surveillance system; (4) continuous virtual reality capability widely available on Earth; (5) in-situ production and storage of propellant, and breathing oxygen; (6) environmental monitoring systems, including radiation, dust, and surface wind monitoring; and (7) long-lived robotic scientific observational systems. In the longer term, the Outposts could augment the capability now envisioned by the robotic program. The Outposts would make good sites for conducting (1) wide band, long duration seismometry; (2) deep (and therefore long-duration) solar powered autonomous drilling with in-situ examination and/or sample return; (3) long-term magnetotelluric studies; (4) long-term robotic traversing and tele-operation, (5) planetary dynamical studies using the long-duration radio direct link; and (6) autonomous launching of scientific balloons and airplanes.

New requirements for the current Mars program: There will be new requirements as well as new opportunities to prepare for the long haul and also to engage sustained human interest in the robotic program as an essential precursor to human involvement. Current Mars exploration planning should be charged with: (1) establishing the physical, topographic and geographic requirements for an integrated robotic/human base (this could include surveys for ground ice at low latitude sites for eventual human use as well as FOR nearer-term scientific exploitation); (2) defining the various possible technical forms of future human occupancy, ranging from the "large, mostly closely-spaced in time" to a "smaller, extended" with more deliberate buildup of infrastructure, in order to better establish the physical requirements for future outposts; and (3) developing an integrated base architecture and initiating key long-term developments such as in-situ resource utilization and autonomous communication and computation infrastructure.

Conclusions: It is important that near-term robotic exploration take place within a grander, public vision stretching out through the eventual human presence on Mars. Definition and targeting of specific sites on Mars as first robotic, and eventually candidate human bases, is valuable and affordable within the context of the robotic program alone, yet can greatly expand the popular interest and significance of that program. The program otherwise lacks a natural climax or defining accomplishment which is widely supported by scientists and the public alike.

The Athena Miniature Rock Coring & Rock Core Acquisition and Transfer System (Mini-Corer). T. M. Myrick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, myrick@hbrobotics.com), S.P. Gorevan, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, gorevan@hbrobotics.com), C. Batting, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, batting@hbrobotics.com),S. Stroescu, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sergiu@hbrobotics.com), J. Ji , (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, chunlei@hbrobotics.com), M. Maksymuk, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, mike@hbrobotics.com), K.R. Davis, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, krdavis@hbrobotics.com) M.A. Ummy, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, ummy@hbrobotics.com), and the Athena Science Team.

Introduction: The miniature rock coring and rock core acquisition and transfer system (Mini-Corer) is a part of the Athena Mars rover science payload. Its major objective is to acquire rock cores for in-situ examination by other instruments of the Athena instrument suite and to provide for a precision caching of the acquired cores for purposes of sample return. The Mini-Corer is a highly developed robotic drill capable of obtaining two 25-mm long and 8-mm diameter cores from the same hole from very strong rocks. The low power Mini-Corer can readily drill 25 mm into strong basalt[1] in less than 6 minutes while consuming less than 10 watt-hours of power. A key feature of the Mini-Corer is its ability to break off the core from the base rock and retain the core. A pushrod internal to the core tube provides for a controlled and positive ejection of the core. This same pushrod is used to stabilize the target rock during the initial coring action. With the autonomous acquisition of a specialized tool, the Mini-Corer also acquires and transfers unconsolidated soil to the return cache. The Mini-Corer employs 5 brushed DC motors equipped with incremental encoders.

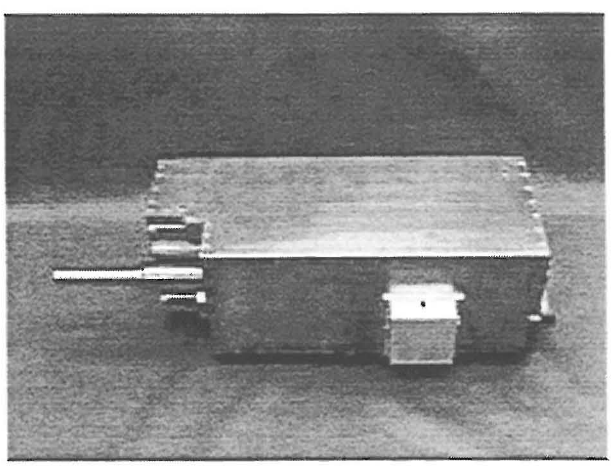


Figure 1: The Engineering Model of the Athena Mini-Corer.

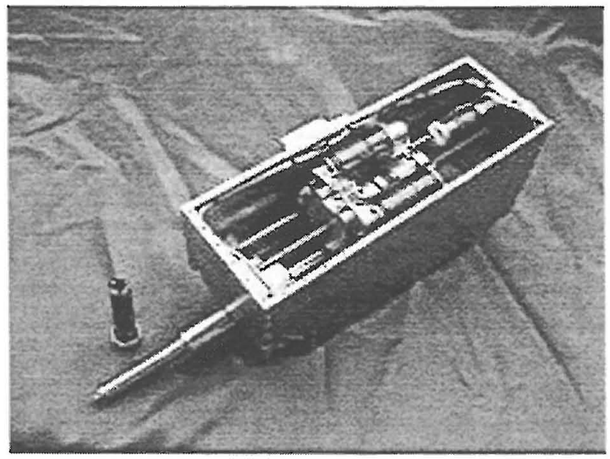


Figure 2. The interior of the Athena Mini-Corer

Initial Entry; Stabilizing The Target Rock With the Pushrod: To facilitate reliable autonomous drilling into small rocks or rocks with an unstable set position and to prevent drill bit "walking" upon initial entry, the internal push rod is used. The pushrod is lowered via the mini-corer z-axis and its own miniature lead screw to make initial contact with the target rock. A thrust force sensor indicates rock contact and the push rod maintains a stabilizing force of about 22 newtons in the direction of drilling. The rotating core tube with its cutting teeth is lowered to the rock surface with the z-axis and commences to cut the rock surface. As the core barrel descends into the rock the pushrod retreats into the Mini-Corer body by the same distance. This synchronous action of the push rod and core tube continues until the core tube tip has acquired a secure bite into the rock.

Breaking off the Core from the Base Rock and Acquisition of the Core: Drilling continues until the desired core length has been reached (depth information is provided by incremental encoders on the z axis drive train). At this point, the core break-off tube begins to rotate to the break-off position. The core tube and the break-off tube are coaxial during drilling. For breakoff, the break-off tube rotates relative to the core tube. With this relative rotation, the two tubes are no longer coaxial. This action shears the core off from the base rock. The relative position of the tubes creates a lip that provides for a positive retention inside the core tube of the broken-off core.

Core Transfer: The Mini-Corer is optimally mounted on the rover such that it can be actuated in both pitch and translation axes. These two axes in conjunction with the z axis of the Mini-Corer can be called upon to position the tip of the Mini-Corer to a core storage location (cache) or in a convenient position for examination of the core tip by the Athena instrument heads mounted on the rover's instrument arm. Once lined up with the core storage location, the break-off tube is commanded to rotate to its original position. The pushrod is then moved to the core ejection position and the core is precisely ejected out of the core tube.

Drill Algorithm: The basic drilling algorithm is based on thrust and torque thresholds. As drilling proceeds normally through the rock, a torque threshold is monitored by the controller. If the torque is sensed to be higher than the threshold, the z-axis retreats a very small amount. The retreat of the drill tip from the rock face reduces the torque. Once the torque drops below the threshold, the z-axis moves toward the rock and cuts more rock until the torque threshold is encountered again and the drilling loop is repeated. If the torque threshold is not encountered, drilling continues until the targeted drilling depth is reached. A thrust threshold is monitored to prevent too much thrust (which might present a risk to the rover) from being reacted into the mini-corer platform.

Science Return from Drill Sensors: Mini-Corer sensor data required for the drilling algorithm generate a signature that correlates with some physical characteristics of the target rock. Torque, thrust and penetration rate data can be inverted and compared to drill performance in terrestrial analogs to arrive at a determination of rock compressive strength and density.

Drill Bits: The cutting teeth on the tip of the Mini-Corer are especially designed to cut into strong rock with a minimum of torque. Currently the teeth in use by the Mini-Corer are made of tungsten carbide. Testing indicates that 8 mm carbide drill tips start to dull after drilling ten 30-mm cores into a basalt with a compressive strength of over 100 Mpa but these bits are still useful. In conjunction with DeBeers, Honeybee Robotics is developing a very long lasting PCD and natural diamond drill tip.

Autonomous Changeout of Drill Bits: The nominal performance goal of the Mini-Corer is to acquire forty 25-mm rock cores with the same drill bit. Should the target rocks be hard enough to dull the bit before 40 cores are acquired, the Mini-Corer is designed with a quick-change bit acquisition capability. Using the z, breakoff and push rod axes, a dull bit is removed from the Mini-Corer tip and a new drill bit is acquired in a make-before-break robotic transfer.

Soil: Employing the same quick-change subsystem used for changing drillbits, the Mini-Corer drill can be commanded to acquire a soil acquisition end effector. This gripper utilizes the pushrod and drill drive train for its operation; no additional actuators are requireed.

Instrument Performance: A 5 mm breadboard version of the Mini-Corer has been successfully field tested aboard JPL's FIDO rover and the 8-mm Athena Mini-Corer is very close to being flight ready. The first 8-mm engineering model Mini-Corer is nearing complete assembly as this abstract is being written. In the last year drill bit design and drilling algorithm advances have reduced power consumption by a factor of five. The Mini-Corer mass is 2.7 kg and the Mini-Corer box dimensions are 29.8 cm x 14.51 cm x 9.64 cm.

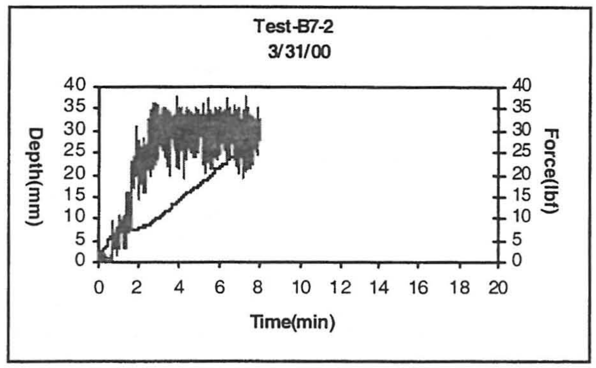


Figure 3 8-mm Drilling into Basalt[2]

References: [1] [2] A Hydrothermally altered quartz tholeiite from the Keweenawan Volcanic Group from the North Shore of Lake Superior. The rock was analyzed as part of the Ph.D. thesis of Joyce Brannon (1984) "Geochemistry of Successive Lava Flows of the Keweenawan North Shore Volcanic Group," Washington University, St. Louis.

RECOMMENDATIONS FOR PRESERVING THE INTEGRITY OF SAMPLES COLLECTED ON MARS AND RETURNED TO EARTH FOR ANALYSIS. C.R. Neal[1], B.L. Jolliff[2], J.J. Papike[3], G. MacPherson[4]. 1: (neal.1@nd.edu) Dept. Civil Eng. & Geological Sciences, Univ. Notre Dame, Notre Dame, IN 46556; 2: Washington Univ., St. Louis, 3: Institute of Meteoritics, Univ. New Mexico; 4: Smithsonian Institution, Washington DC.

Introduction: As part of an integrated approach to planetary exploration [1], samples will ultimately be returned from Mars to Earth for analysis. This will be the next logical step in our exploration of the red planet as we strive to learn more about its evolution and investigate the possible occurrence of life on Mars. NASA'a Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) has been studying the preservation issues for returning geological samples from Mars [2,3]. The overriding goal of these studies has been the preservation of pristine Martian signatures in the returned samples, thus maximizing the scientific value of such missions. Preventing contamination/alteration is particularly critical for chemical, biological, and morphological signatures that are indicative of life, either extinct of extant. Such prevention is required for the short term during collection, transport, and re-entry & impact on Earth, as well as for long term curation. In this presentation, we discuss contamination issues within the framework of an Athena-like sampling mission; however, the concepts may be extrapolated to other plausible sampling scenarios. Issues encompassing preservation from the successful collection, to return to Earth, and curation of martian samples are discussed within this framework. We build upon earlier reports [e.g., 4-7], and complement(?) the recent MSHARP report [8] by concentrating -on the samples themselves. Below is a summary of recommendations made by CAPTEM that will maximize the scientific value of any returned Martian samples. These recommendations are made, for the most part, with consideration of the stringent budgetary constraints that will be part of any sample return mission to Mars.

The governing principle behind this study is that any procedure or piece of equipment that can impact (contaminate) the Mars samples during collection, transportation, or curation needs to be fully evaluated through analysis and experimentation ***prior*** to implementation by a scientific committee, that has expertise in extraterrestrial sample analysis, curation, and preservation.

Spacecraft: Transportation of organic material from Earth to Mars could result in bio-organic contamination of the returned samples resulting in "false positives" when the samples are examined for signs of life. In turn, this may cause unnecessary delays in releasing the samples to the scientific community. Therefore, the spacecraft cannot just be sterilized, but the dead bacteria, etc., need to be removed.

Sample Collection: Contamination of samples is possible from contact with any rover components, ranging from *in-situ* analytical instruments to the wheels, and contact with parts of drilling or caching mechanisms. For rock coring, tungsten carbide will likely be used for the drill bit as it is the best material for this endeavor. CAPTEM endorses the use of a coring system to acquire fresh, unweathered samples. However, of all the potential sources of contamination during sample collection, contamination from a coring device is likely to be geochemically the most severe(?). Contamination of the samples via the drill bit could potentially compromise trace element (e.g., Zr, Nb, Hf, W, C, platinum group element) and isotopic (e.g., W-Hf, Lu-Hf, Re-Os, Pt-Os) analyses.

Assuming a coring device is used, each rock selected for sampling should have multiple cores extracted (5-10 g per rock). Although essential geoscience studies on most individual rocks **can** be done with fine-grained samples as small as 5 grams, a larger sample mass is desirable for coarse-grained rocks. Even for fine-grained rocks, 5 grams will leave little or no reserve material for future studies. It is estimated that a minimum of approximately 10% of each sample (0.5-1 gram) will be required for planetary protection studies. 1-2 g of material is desirable for determinations of trace organic constituents. Therefore, while we accept 5 grams per rock as a minimum mass, we urge where possible to exceed this mass up to a total of ~10 grams or equivalent to 4 cores per rock.

The Samples: A diverse suite of samples should be returned in order to conduct broad-based investigations into the evolution of Mars [2]. If analyses are to be conducted on Earth, it is highly desirable that these samples be preserved in their pristine condition during collection, travel back to Earth, and analysis/curation.

Sample Containment: As the samples will be contained for a relatively long period, the container should not compromise sample integrity. In addition, temperature control will be important for preserving sensitive biologic/chemical signatures. If Teflon is to be used, it should be PFA or FEP and applied as a baked-on coat to the metal of the sample container, rather than a separate insert. This protocol reduces the number of parts to be manipulated, and the possibility that the sleeve could come loose, preventing sample insertion, is avoided. Mixing of samples is considered undesirable especially if a petrologically diverse suite of samples is returned from different areas around the landing site(s).

Materials: A clear understanding of how any drill will operate, along with any sample contamination problems, should be acquired through extensive testing of such a drilling system prior to assembly of the spacecraft. As far as possible within mission/curation constraints, only *pure, homogeneous* materials should be used for components that come into contact with the samples. Materials that would be acceptable from a sample contamination standpoint are:

- Low-Zn aluminum (i.e., not the 7000 series alloys) - the 6061 alloys (i.e., alloyed with Mg and Si) are acceptable;
- Low sulfur stainless steel that contains no molybdenum and is compatible with electropolishing and passivating in nitric acid;
- Titanium alloys should be as pure as feasible given the required physical and metallurgical properties;

RECOMMENDATIONS FOR MARS SAMPLE RETURN: C.R. Neal et al.

- Unplasticized Teflon that would impart organic contamination recognizable as non-biogenic;
- Tungsten carbide used for the drill bits should be pure WC and sample contamination documented through drilling experiments on Earth.

Such materials should be analyzed for organic and inorganic constituents using at least two different analytical techniques. This will either demonstrate the purity of the substance or allow an understanding of the nature of potential contamination through quantifying the impurities present.

Sterilization: While the probability of the returned samples containing viable organisms cannot be demonstrated to be zero, it is considered to be extremely low [7,9,10]. We suggest that if a sample contains no organically bound carbon or demonstrably viable organisms, it be released for scientific study. If sterilization is required, we recommend that heat and chemicals NOT be used as these methods severely compromise sample integrity; at present, the preferred sterilization method is high-dose gamma radiation [11].

Curation: Long term curation of martian samples on Earth will utilize procedures and protocols developed for lunar samples, cosmic dust, and meteorites that will preserve the integrity and pristinity of returned samples. However, protocols need to be reviewed and modified to meet the challenges of curating samples in the long term. For example, storage of the samples should be ~240 K and under an inert atmosphere (e.g., nitrogen) for long term preservation of low-temperature chemical signatures and prevention of isotopic exchange. The need to keep bio-organic contamination out of the sample containers and the curation facility will require an examination of air filtration requirements and protocols.

RECOMMENDATIONS: The following is a list of CAPTEM recommendations for ensuring the pristinity of returned Mars samples (see [2,3]):

The spacecraft needs to be sterilized and cleaned at least to Pathfinder standards, with the components that come into contact with the samples having a higher degree of cleanliness. Use of witness plates for this endeavor is essential, as they could prove to be useful in documenting forward contamination.

Drill-bit contamination needs to be thoroughly investigated through experiments and component analysis on Earth; the composition of the drill bits should be characterized with detailed chemical and isotopic analysis. This should also be applied to any lander-based regolith/rock drill.

A variety of sample gathering devices e.g., scoop, drills) should be flown on the rover and lander to allow the collection of a diverse suite of samples and, most importantly, to enable the return of samples if any one sample collection system fails.

The sample caching container should be constructed out of the purest materials possible, allow for no cross contamination between potentially diverse samples, keep rock cores separate from each other and from unconsolidated regolith samples, and be sealed on the surface of Mars.

Regolith core from any lander-mounted drill be kept separate from the rover regolith sample(s) thief the former are contaminated with and disturbed by rocket exhaust.

The temperature of samples be kept at, or ideally below 240K.

There should be no artificial tracer placed in the drill bit because the deliberate contamination by the addition of tracers will interfere with data interpretation.

Only the purest of materials should be used for components coming into contact with the samples. Materials used in spacecraft construction (i.e., those that will come into contact with the samples) should be fully characterized and a database created during the manufacturing stage of the components (whether for spacecraft or the receiving/curation facility).

The preferred sterilization method is high dose gamma radiation as it will have little impact on the chemical or morphological signatures of the samples.

We recommend that a thorough review of curatorial procedures and protocols be conducted (and amended accordingly), prior to the return of the samples, and new protocols formulated to address the unique challenges of long term martian sample curation/preservation.

References: [1] CAPTEM (2000) This Wksp; [2] Jones J.H. & Treiman A.H., (1998). *Lunar & Planetary Institute*, http://cass.jsc.nasa.gov/captem/mars.html; [3] Neal (2000) JGR Planets (in press); [4] JSC (1974) *NASA JSC, Houston TX*, 318p.; [5] JSC (1977) *Lunar & Planetary Sciences Division, NASA JSC, Houston, TX*, 76 p.; [6] Gooding (1990) *NASA Technical Memo 4184*, 32 p.; [7] NRC (1997) *Mars Sample Return: Issues and Recommendations*, 47 p. National Academy Press; [8] Carr, M.H. (1999) *Mars Sample Handling and Requirements Panel (MSHARP) Final Report*, February 8, 47 p.; [9] Mars Expeditions Strategy planning Group (1996) The Search for Evidence of Life on Mars. http://www.hq.nasa.gov/ office/oss/mccleese.htm, 8 p.; [10] Space Studies Board (1998) National Research Council, 100 p.; [11] Allen C. C. (1999) *JGR 104*, 27,043-27,066.

IN-SITU MEASUREMENTS OF COSMOGENIC RADIONUCLIDES ON THE SURFACE OF MARS.

K. Nishiizumi[1] and R. C. Reedy[2], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu), [2]Space and Remote Sensing Sciences Group, MS-D436, Los Alamos National Laboratory, Los Alamos, NM 87545, USA (rreedy@lanl.gov).

Introduction: Cosmogenic nuclides are produced by cosmic-ray nuclear interactions with target nuclei in rocks, soils, ice, and the atmosphere. Cosmogenic nuclides have been widely used for investigation of solar system matter for several decades [1]. Stable nuclides, such as ^{3}He, ^{21}Ne, and ^{38}Ar, are built up over time as the surface is exposed to cosmic rays. The concentrations of cosmogenic radionuclides, such as ^{10}Be (half-life=1.5 Myr), ^{26}Al (0.705 Myr), and ^{14}C (5,730 yr) also build up with exposure time but reach saturation values after several half-lives.

Especially after development of accelerator mass spectrometry (AMS), cosmogenic nuclides in terrestrial samples are routinely used for geomorphic studies such as glaciation, surface erosion, and tectonics, and studies of atmospheric and ocean circulation [2]. Cosmogenic nuclides on Mars will be able to answer questions of exposure ages, erosion rates, tectonic events, and deposition rates of sediments and/or volatiles. The concentrations of cosmogenic stable nuclides gives the integrated exposure time of the rock/mineral, and the activities of radionuclides give recent records for times back as long as a few half-lives.

Cosmogenic Nuclides on Mars: Unlike on the Earth, the cosmic rays readily reach the Martian surface because of its thin (~15 g/cm^2) atmosphere and very weak magnetic fields. The cosmogenic nuclide production rate and profiles in the Martian surface are similar to those on the Moon, even after taking into account the average Martian atmospheric depth of 15 g/cm^2 [3]. The production rates of various cosmogenic nuclides on Mars can be calculated using LAHET Code System that has been well tested using a database of cosmogenic-nuclide observations in lunar, meteoritic, and terrestrial samples. Because the production rates on Mars are 3 orders of magnitude higher than those on the Earth's surface, at levels like those in meteorites and lunar samples, many cosmogenic nuclides can be measured in Martian surface features.

Although production rates of nuclides on the Martian surface are similar to those in extraterrestrial materials, the application of cosmogenic nuclides are somewhat similar to terrestrial applications [4]. The terrestrial applications of cosmogenic nuclides have included erosion and exposure histories (by glaciation, floods, landslides, faults), ages of impact craters, deposition or ablation of soils and icecaps, and ages of young volcanic eruptions. Steady state erosion of bedrock surfaces may give information on long-term erosion rates of the Martian surface. The histories of aeolian dust and layered terrains near the poles can also be studied. The use of multiple cosmogenic nuclides is required to constrain exposure histories of Martian surface samples.

The promising nuclides for up to 10^{6}-10^{7} years of histories on Mars (^{14}C, ^{36}Cl, ^{26}Al, ^{10}Be, ^{53}Mn, ^{3}He, and ^{21}Ne) are those often used to study other extraterrestrial materials. The ^{10}Be-^{26}Al-^{21}Ne combination is very good for solving complex histories of terrestrial surface morphologies as well as histories of meteorites. However, all of these cosmogenic nuclides can be measured only in returned samples at the present detection methods.

The radionuclide ^{14}C made in the Martian atmosphere has been proposed to study the nature of atmosphere-regolith interactions [5]. However, the Martian atmosphere is so thin that production of ^{14}C in soil nitrogen could be a serious complication [6]. Some cosmogenic radionuclides made in the Martian atmosphere could be deposited on the surface, as is the case for terrestrial cosmogenic nuclides.

The global surface chemical composition of Mars can be mapped by orbital gamma-ray measurements [7], and a Ge gamma-ray spectrometer is scheduled to fly on the Mars 2001 orbiter. However, the gamma-ray flux is dominated by prompt gamma rays, with decay gamma rays generally having much weaker fluxes.

Detection of Cosmogenic Radionuclides on the Surface of Mars: Because the production rates of cosmogenic nuclides on Mars are high, the activities of some cosmogenic radionuclides can be detectable on the surface of Mars. An excellent candidate is ^{26}Al, but other nuclides, such as ^{22}Na (half-life=2.61 yr), ^{54}Mn (312 d), ^{60}Co (5.27 yr), as well as ^{40}K and the U-Th decay chains can be measured.

However, the high cosmic-ray intensity increases detector background levels. This requires massive shielding for detectors or coincidence and/or anti-coincidence counting systems. However, massive shielding is not practical on the surface of Mars except by putting detector systems into deep cores or tunnels.

The γ-γ coincidence method is a good technique for the detection of several important radionuclides. The coincidence can be obtained with two gamma-ray detectors in order to reduce background level. For ^{26}Al measurements, using the 0.511 MeV-1.809 MeV coincidence eliminates the interference of $^{26}Mg^*$ prompt γ rays of 1.809 MeV in addition to the reduction of background. For ^{22}Na measurements, the 0.511 MeV-1.275 MeV coincidence can be used.

^{22}Na-^{26}Al pair: Both nuclides are produced similar nuclear reactions. The ratio and activities of two nuclides will tell us recent geometry and histories. ^{22}Na can give the sample's geometry during the last 5 years and the prediction of the ^{26}Al production rate at that location. ^{26}Al can be used to determine the exposure time at the location or average shielding depth or gardening rate of regolith samples. Further more, combining of ^{22}Na-^{26}Al and proposed *in-situ* noble gas measurement (^{21}Ne) in the same sample would provide both erosion rate and exposure age.

The gamma-ray spectrometer used to measure cosmogenic nuclides could simultaneously be used to determine the surface's elemental composition. Unlike an orbital gamma-ray spectrometer, which detects individual gamma rays [7], our surface system would use gamma rays in coincidence. Gamma-ray pairs (energies in MeV) that could be used to measure elements include: 2.741-6.129 for O, 1.369-2.754 for Mg, 4.934-3.539 for Si, any two of the 5.421-2.380-0.841 cascade for S, any two of the 6.111-0.517-1.951 cascade for Cl, 6.419-1.943 for Ca, 6.760-1.382 for Ti, and 5.920-1.725 for Fe.

The γ-ray detector system can be also used for *in-situ* instrumental neutron activation analysis using a ^{252}Cf or other removable intense source of low-energy neutrons.

There are some technical problems in using germanium gamma-ray detectors. The Ge detectors would have to be cooled to ~100 K when they are used. A passive radiator, like that proposed for a Ge gamma-ray spectrometer on a Rosetta comet lander [8], could be used at night. Operation of Ge detectors would be easier in winter or near the Martian poles. Radiation damage is a problem with Ge detectors, and the ability to anneal the Ge detectors might be needed. The weight and power for a Ge gamma-ray detector system might be fairly high.

Another good detector system for Martian surface gamma-ray measurements could be made using CdZnTe room-temperature solid-state detectors [9]. While the energy resolution is not as good as Ge, it is good enough (about 2%) for use in a coincidence system and would be lighter and more compact.

Conclusion: The measurement of multiple cosmogenic nuclides is required to understand surficial histories of Mars. The high cosmogenic nuclide production rates on Mars allow us to use multiple nuclides as in studies of terrestrial samples, meteorites, and lunar samples. Although sample return is extremely important for such studies, we feel that *in-situ* gamma-ray measurements of cosmogenic nuclides on Mars during future missions can provide valuable information about the history of the Martian surface.

Acknowledgement: This work was supported by NASA and DOE grants and the work at Los Alamos was performed under the auspices of the US Department of Energy.

References: [1] Reedy R.C. *et al.* (1983) *Annu. Rev. Nucl. Part. Sci. 33*, 505-537. [2] Tuniz C. *et al.* (1998) *Accelerator Mass Spectrometry* 1-371. [3] Masarik J. and Reedy R.C. (1995) *Lunar Planet. Sci. XXVI*, 901-902. [4] Nishiizumi K. *et al.* (1993) *Earth Surf. Process. and Landforms 18*, 407-425. [5] Jakosky B.M. *et al.* (1996) *J. Geophys. Res. 101*, 2247-2252. [6] Masarik J. and Reedy R.C. (1997) *Lunar Planet. Sci. XXVIII*, 881-882. [7] Masarik J. and Reedy R.C. (1996) *J. Geophys. Res. 101*, 18891-18912. [8] d'Uston C. *et al.* (1996) *Lunar Planet. Sci. XXVII*, 327-328. [9] Moss C.E. *et al.* (2000) *Lunar Planet. Sci. XXXI*, CD-ROM, Abstract #1827.

Colliding Beam Fusion Electric Power System for Mars Exploration. Joseph A. O'Toole[1], Frank J. Wessel[2], N. Rostoker[2], and M. Binderbauer[2], [1]Los Alamos National Laboratory, 1663 Bikini Atoll Road, MS H805, Los Alamos, 87545, [2]University of California, Department of Physics and Astronomy, Irvine, CA 92697-4575.

Introduction: Exploration of Mars, by robotic means and eventually manned exploration, will require significant levels of reliable, high-density electric power. An electric power system based on fusion energy possesses distinct advantages. If developed successfully fusion energy sources would be characterized by high fuel energy density, low system mass, modest fuel requirements, and the abundance of fuel sources throughout the solar system. NASA plans a FY01 new program start with a goal of realizing a fully operational fusion space propulsion system within 20 years; a similar time frame as envisioned for the MARS Exploration Initiative. The development milestones for a planetary-based power system and space propulsion system are synergistic extensions of our existing efforts to develop an Earth-based energy source. This paper reviews the scientific and technology base for our design and describes options for the use of this technology on a Mars mission.

Near term power for planetary exploration: We begin by considering the Colliding Beam Fusion Reactor (CBFR). [1], [2], [3] In a CBFR the plasma core is confined inside a "high beta" ($\beta \equiv$ plasma pressure / magnetic pressure) magnetic cavity that extends along the axis of the cylindrically symmetric system. Such a compact, high-beta system is characterized by a reversal in the direction of the applied magnetic field, on-axis, and the absence of appreciable magnetic field within the fusion core plasma; it is generally referred to as "field-reversed configuration" (FRC). [4] The plasma in an FRC sustains a large circulating current, hence generating a self-magnetic field that adds to the ambient field. Injected ion beams (E_{ion} ~ 1 MeV) maintain the current and replenish the spent fuel. In the confined-ion frame-of-reference the particle distributions are thermal and the circulating current is unneutralized. The ions orbit size is comparable to the dimensions of the system, hence classical transport of the particles and energy are predicted, reducing the size and mass of the system by many orders of magnitude compared to other fusion concepts. Finally, beam injection enables the use of aneutronic fusion fuels. The reaction product of such fuels are predominantly charged particles that can be collimated efficiently along the axis of the open-ended system, and converted directly to electric energy. The system scales well to low power, and with heavy nuclear shielding not being required, results in a compact, light weight system suitable for deployment.

We have evaluated the confinement physics in a CBFR based on the Vlasov-Maxwell equation, including a Fokker Planck collision operator and all sources and sinks for energy and particle flow. The results indicate that the CBFR could be scalable in the output power range of 10^6-10^9. Most, if not all of the critical technologies needed to demonstrate the CBFR readily exist: superconducting magnets, vacuum systems, beam injectors, etc. Moreover, low energy, pulsed FRCs have already attained parameters close to the range needed for fusion energy. A 50 MW electric power system might involve the following (approximate) design parameters: 1-meter diameter, 7-meters length, magnetic field ~ 7 Tesla, ion beam current ~ 10 A, and fuels of either D-He^3, P-B^{11}, P-Li^6, D-Li^6, etc.

A description of the electric power system and its function will be discussed, along with a development time-scale, followed by some options for its use in Mars explorartion.

The R&D milestones for our Earth energy research program are to complete phase 0 - scientific feasibility, phase 1 – engineering feasibility, and phase 2 – commercial feasibility within a three to six-year period. Appropriate modifications to this schedule would be possible to reflect efforts related to space propulsion /planetary power system testing.

References: [1]N. Rostoker, M. W. Binderbauer, H. J. Monkhorst, Science 278, p. 1419(1997). [2]N. Rostoker, F. J. Wessel, H. U. Rahman, etc. Al. [3] http://fusion.ps.uci.edu. [4] M. Tuszewski, Nuclear Fusion 28, p. 2033(1988).

Mars Exploration Strategies: Forget About Sample Return! D. A. Paige, Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095. dap@thesun.ess.ucla.edu.

Introduction: During the past months, loss of the Mars Climate Orbiter and Mars Polar Lander spacecraft have received considerable attention. In reality, NASA's toll of lost missions during this period has been much higher due to the cancellation of the Mars 2001 lander mission and the failure to plan a credible Mars sample return mission. NASA has commissioned a number of internal and independent investigations which have focused on the technical and management failures that were responsible for the failures of the '98 missions. However, the even more serious setbacks that the future missions in the Mars Surveyor Program are experiencing have not received the same degree of critical attention. In this paper, I attempt to identify some of the key science strategy issues relating to these problems, and suggest returning to a strategy for Mars exploration that is more closely aligned with reason, risk avoidance, and reality.

The Pre-1996 Strategy: In the course of researching this abstract, I read through the various Mars strategy documents that have been produced by NASA, JPL and the National Research Council over the years. One of the most well-reasoned was produced in January 1995 at the request of Michael Meyer of NASA's Exobiological Program Office, and is entitled "An Exobiological Strategy for Mars Exploration". The study advocates dividing the search for past and present life on into a logical sequence consisting of 5 phases, which are:

Phase 1. Global Reconnaissance, focusing on the past and present role of water, and the identification of sites for future, detailed study.

Phase 2. In-Situ Exploration of Promising Sites, focusing on describing their geologic, mineralogic, elemental, and isotopic characteristics, as well as the abundance and distribution of volatile species and organic molecules.

Phase 3. Deployment of Exobiologically-Focused Experiments, to provide detailed characterizations of the population of organic compounds, and to search for biomarkers of formerly living organisms, and extant life.

Phase 4. Robotic Return of Martian Samples to Earth, to improve the characterization of organic compounds, and to verify any evidence for biomarkers and extant life discovered in Phase 3.

Phase 5. Human Missions, providing detailed scientific characterizations of sites of unusual biologic interest, or sites that are inaccessible to robotic exploration.

This report, which was produced before the hoopla associated with the Mars Pathfinder landing and the "Mars Rock Discoveries" in 1996, provides a clear, step-by-step approach to answering the question of whether or not life ever emerged on Mars that takes proper account of our lack of scientific knowledge regarding the planet Mars, the distinct possibility of ambiguous results and interpretations of scientific data, as well as the significant technical challenges, risks and timescales associated Mars exploration. It is not a comprehensive strategy in that it is focused on exobiology and does not thoroughly consider investigations of the solid planet, the atmosphere and climate, and preparation for human exploration. However, it does provides a good model for how to accomplish a high-level scientific goal through a series of missions.

The Post 1996 Strategies: After 1996, the Mars program began attracting considerably more attention than it had in previous years, and I would argue, became a victim of its own success. After 1996, we saw significant increases in a) the level of visibility, interest and participation in the Mars program, b) the level of funding for Mars activities, c) the administrative levels at which planning decisions regarding the Mars program were being made) d) the overall level of naivete regarding scientific and technical issues associated with Mars exploration that was injected into the planning process. For instance, the successful Mars Pathfinder landing was interpreted by many to suggest that even more ambitious surface missions could be accomplished at even lower cost. In retrospect, we now know that the success of Pathfinder was the result of a very shrewd management approach which maintained large margins in all areas, including scientific performance, as well as very careful attention to testing. We now know that anything less thorough than Pathfinder will probably result in a developmental or mission failure. Also, the fact that credible scientists found "evidence for ancient life" in the ALH84001 meteorite was interpreted by some to suggest that such exciting evidence may be much more ubiquitous on the/ surface of Mars than had previously been imagined, and that confirming the ALH84001 discoveries would only be a matter of returning a suitable sample to Earth for detailed analysis. However, in retrospect, we now know that much of the evidence for ancient life found in the "Mars rock" is ambiguous or debatable, and that similar issues are likely to arise when robotically acquired samples are eventually returned to Earth. We also now have a deeper appreciation for the fact that Mars is a really big place with a complex history to unravel, and that it will take quite a lot of evidence to prove that life ever existed on Mars, or quite a lot of searching to prove that it never did.

During the 1996-2000 period, the incorrect notion that Mars exploration might be "quicker and easier" than thought previously led to a certain degree of impatience with the orderly process of scientific exploration that had been advocated previously. A number of attempts were made to create "leapfrog" architectures in which Phase 4 sample return missions came directly on the heels of Phase 1 global reconnaissance missions, skipping Phase 2 and Phase 3 altogether. The net result of this accelerated approach has led to a series of failed mission concepts for the '01 and '03 opportunities that in total, will probably end up costing the community about four years and on the order of 1 billion dollars.

The Misguided Emphasis on Early Sample Return: One of the most prominent aspects of the failed 1996-2000 exploration architecture plans was to accomplish the goal of sample return at the earliest possible opportunity. One could argue on philosophical grounds that this aggressive approach is in keeping with established pattern of human technological and explorational accomplishments, i.e. that most goals are achieved soon after they are technically feasible, and that the publicly stated justifications for accomplishing these goals often have little to do with reality. For the case of Mars sample return, there has been a strong tendency to equate the analysis of returned samples with "good science", and while it is undoubtedly true that one could do a lot of good science on returned samples, we are a long way from a situation where sample return is *necessary* to make further scientific progress towards the overarching goal of understanding whether life ever arose on Mars. If we use the phased exploration strategy advocated by the exobiologists in 1995 as a model, the Mariner 9, Viking and MGS orbiter data sets have/will provide a good deal of the global reconnaissance required in Phase 1, and the Viking and Pathfinder landers represent just the beginning of the in-situ analysis required in Phase 2. Simply put, from a scientific and technological standpoint, we are not at Phase 4 yet. We don't know where to go on Mars to get the samples we need to answer the life on Mars question, nor do we know how to design and build the vehicles and systems we need to accomplish a successful sample return mission, especially within the current resources of the Mars program. Putting sample return first is an extremely low-pay-off strategy that in most games, would signal naiveté, impatience, dishonesty or desperation.

A Post 2000 Strategy: The serious setbacks that have been experienced by the Mars program in recent months have provided us with a unique opportunity to reassess where we are going and what we are attempting to accomplish. I believe that the question of whether or not life ever arose on Mars provides a good unifying theme for the program. However, as has been pointed out in independent assessments of NASA's Mars exploration architecture by COMPLEX and elsewhere, that a definitive scientific answer to this question will require the accomplishment of a broad range of scientific investigations of all aspects of the planet – not just the analysis of a few grams of the first rock samples.

Since 1995, we have learned nothing which suggests that a phased exploration strategy as advocated by the Exobiologists should be substantially modified. The only outstanding issues relate to the pace of the program and its breadth. Clearly, the events of the last months have made it clear the "leapfrogging" is not going to work - not from a scientific standpoint, nor from a technological standpoint either. The notion that the next site we land at must necessarily be *the* site that we go to collect the first set of returned samples has got to be discouraged if we are ever going to explore the true diversity of the planet and its environmental history. Right now, we posses the technology and the resources to do a first-rate job of Martian global reconnaissance and in-situ exploration of a wide variety of sites.

There will always be scientists with laboratories who will advocate that NASA provide them with Mars samples for them to analyze. The fact is, however, that we don't yet have the technology to do this within acceptable levels of cost and risk. Those who are anxious to move the program forward toward sample return have more than enough to do in the areas of basic technological development, risk reduction and testing.

As we are able to attract more resources to the program, it is vital that we use them to in manner which maximizes program's excitement and further increases its scientific integrity. Key to this integrity is an increased emphasis on program breadth – to not just focus on the "life on Mars question", but to broaden the range of inquiry to encompass all relevant Mars science disciplines. While some may find this broad-based approach frustrating, one can point to a number of examples in the fields of earth and planetary sciences where the most important breakthroughs in real understanding have come from the comparison of data acquired from multiple disciplines. I believe that it is only through this approach that we will ultimately unlock the many secrets that the Red Planet has in store.

After the Mars Polar Lander: Where to next? D. A. Paige[1] , W. V. Boynton[2], D. Crisp[3], E. DeJong[3], C. J. Hansen[3], A. M. Harri[4], H. U. Keller[5], L. A. Leshin[6], R. D. May[7], P. H. Smith[2], R. W. Zurek[3], [1]Dept. of Earth and Space Sciences, UCLA, Los Angeles, Ca 90095 dap@mvacs.ess.ucla.edu, [2]University of Arizona,. [3]Jet Propulsion Laboratory, [4]Finnish Meteorological Institute, [5]Max Planck Institute for Aeronomy, [6]Arizona State University, [7]Spectrasensors Inc.

Introduction: The recent loss of the Mars Polar Lander (MPL) mission represents a serious setback to Mars science and exploration. Targeted to land on the Martian south polar layered deposits at 76° S latitude and 195° W longitude, it would have been the first mission to study the geology, atmospheric environment and volatiles at a high-latitude landing site. Since the conception of the MPL mission, a Mars exploration strategy has emerged which focuses on Climate, Resources and Life, with the behavior and history of water as the unifying theme. A successful MPL mission would have made significant contributions towards these goals, particularly in understanding the distribution and behavior of near-surface water, and the nature and climate history of the south polar layered deposits. Unfortunately, due to concerns regarding the design of the MPL spacecraft, the rarity of direct trajectories that enable high-latitude landings, and funding, an exact reflight of MPL is not feasible within the present planning horizon. However, there remains significant interest in recapturing the scientific goals of the MPL mission. The following is a discussion of scientific and strategic issues relevant to planning the next polar lander mission, and beyond.

Volatiles and Atmospheric Measurements: MPL included the most sophisticated package of meteorology and volatile-sensing instruments ever flown. Its deployment at a high-latitude landing site during the late spring season would have provided the first opportunity to characterize global-scale weather patterns in the southern hemisphere, as well as measurements of the abundance of water ice and adsorbed water and carbon-dioxide in the soil, and water vapor in the overlying atmosphere. These would have been combined with orbital atmospheric sounding and general circulation models to provide a much better picture of the behavior and distribution of water on Mars. In-situ measurements like those intended by MPL are the only means of obtaining this type of information, and should definitely be repeated in future polar lander missions.

MGS Results: In 1995, when the concept for the MPL mission was originated, our understanding of Mars was based almost exclusively on then Viking and Mariner 9 datasets. Since that time, the Mars Global Surveyor (MGS) orbiter has provided significant new datasets which are revolutionizing our understanding of the planet. The MGS results in the north and south polar regions that have been published to date have been particularly exciting. MOLA topographic maps show that both polar caps have approximately 3 km of total relief; and have shapes that are consistent with those expected for large ice sheets. The MOLA data also suggest that both caps may have been significantly larger at some point in their past history [1]. The north polar cap lies in a regional topographic depression which may have once held an ancient ocean. The south polar deposits lie on a regional topographic high[2] , and show distinct evidence for glacial flow [1]. Both polar regions show evidence for the outflow of liquid water into surrounding depressions [2]. In the south, the flow of water can be traced into the Argyre basin, and then across the equator into the northern lowlands [3]. The high-resolution MOC images of the north and south polar caps show a diverse array of fresh surface textures on the residual caps and associated layered deposits which suggest that the polar regions are not presently being "mantled" by dust and ice as thought previously, but instead are being actively modified by processes that have as yet, been not defined [4,5]. In total, the MGS data suggest that the Martian polar regions we see today are the product of a complex climatological and hydrological history which may be intimately connected to the climatological and hydrological history of the planet as a whole.

Polar Landing Sites: MPL was the first Mars mission whose scientific strategy was driven by the desire to obtain detailed measurements at a pre-chosen landing site. Because of their extensive geographic extent, and the expected uniformity in their morphological characteristics, the south polar layered deposits represented an excellent target for the first polar lander mission. The north residual cap is another good example of a large, relatively homogeneous target. However, as we study the Martian polar regions in greater detail, it is becoming clear that to sample the true diversity of polar terrains, and to reconstruct the geologic and climatologic history they may contain, many more landings will eventually be required. In many cases, a precision landing with an error ellipse of less than 5 km would be required to enable detailed examination of specific features of great scientific interest, i.e. an exposure of layers or a suspected ancient outflow channel or esker deposit.

The Desirability of Landing Robustness and Mobility: One of the key new pieces of information that the MGS MOC images have provided, is that polar terrains that appear to be smooth and homogeneous at 1000m scales, are definitely not smooth and homogeneous on 10 m scales. Figure 1 shows examples of high-resolution textures in the north and south polar regions revealed by MOC.

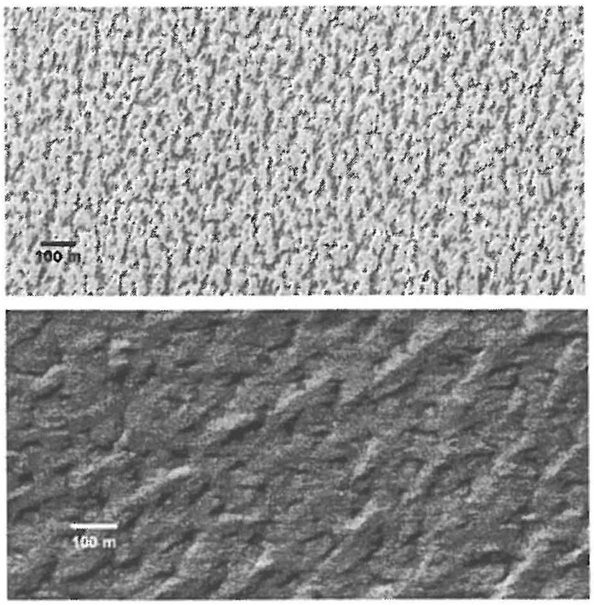


Figure 1. MGS MOC images of surface textures at the Martian north residual water ice cap (top), and south polar layered deposits (bottom). [6]

The implications of this new information are two-fold. First, a robust landing system will be required to ensure safe landings on most polar terrains. Second, a mobile traverse of on the order of 200m should be sufficient to sample the fine-scale diversity of most polar terrains.

Instrumentation: The MPL MVACS payload developed a number of new experimental approaches and technologies that were successfully demonstrated in testing. The use of a dexterous, multi-jointed robotic arm to obtain surface and subsurface soil and ice samples within a wide workspace appears to be a very flexible approach that can be adapted to a wide range of future mission scenarios. Tests of the TEGA instrument demonstrated excellent sensitivity the presence of water ice and hydrated minerals in soil samples. The use of Tunable Diode Laser Spectrometers (TDL) to measure the concentration of water vapor and carbon dioxide gas in the Martian atmosphere, and in evolved gases from heated soil and ice samples is a powerful and robust approach. Improvements in TDL technology in future mission should enable detailed *in-situ* characterizations of the isotopic composition of Martian water and carbon-dioxide. The use of a focusable camera mounted on the robotic arm that can obtain close-up images of the surface and samples is also a very powerful technique that can be extended to true microscopic resolution on future payloads.

Future polar lander payloads should also include newly-developed instruments which could take advantage of the sample acquisition and analysis capabilities of the MVACS payload in a complimentary manner. For example, the addition of an organics detection experiment could significantly extend the search for near-surface organics begun by the Viking landers during the 1970's to environments that could have a greater potential for the preservation of organics.

Conclusions: While the near-term prospects for recovering the scientific objectives of the MPL mission are uncertain, it is clear that an integrated scientific strategy to study Mars' climate, resources and life must include detailed study of the polar regions at multiple landing sites. The MGS results indicate that both the north and south polar regions contain a number of sites of high-scientific interest, and that with foreseeable improvements in our capabilities for robust, precisely-targeted landers, these sites should be accessible to the next generation of Mars landers.

The scientific strategy advocated here is basically an extension of that originally employed for MPL. It starts with the selection of a specific landing site of high-scientific interest, followed by the design of a flexible integrated payload package that is capable of characterizing its environmental conditions, the abundance and behavior of its volatiles, and the fine-scale composition and geology of its deposits at and below the surface. While the return of samples from polar sites may result in significant additional science return, we are presently very far from a situation where sample return is *required* to make further scientific progress. Instead, we would argue that Mars science would be best served by a series of reliable *in-situ* missions which explore the diversity of the Martian surface environments, including those found at the north and south polar regions.

References: [1] Head, J. W. (2000) *LPS XXXI.* [2] Smith, D. et al. (2000) *LPS XXXI.* [3] Parker, T. J., Clifford S. M. and Banerdt, W. B. (2000) *LPS XXXI* [4] Malin, M. C. and Edgett, K. S. (2000) *LPS XXXI.* [5] Thomas etal. (2000) *LPS XXXI.* [6] MSSS Website (http://www.msss.com)

***ALADDIN*: EXPLORATION AND SAMPLE RETURN FROM THE MOONS OF MARS.** C. Pieters[1], A. Cheng[2], B. Clark[3], S. Murchie[2], J. Mustard[1], J. Papike[7], M. Zolensky[5] [1]Brown Univ., Providence, RI 02912; [2]Johns Hopkins Univ. Applied Physics Lab., Laurel, MD; [3]Lockeed Martin Astronautics, Denver, CO; [4]Univ. New Mexico, Albuquerque, NM, [5]NASA Johnson Space Center, Houston, TX

Mission Overview: Aladdin is a remote sensing and sample return mission focused on the two small moons of Mars, Phobos and Deimos. Understanding the moons of Mars will help us to understand the early history of Mars itself. Aladdin's primary objective is to acquire well-documented, representative samples from both moons and return them to Earth for detailed analyses. Samples arrive at Earth within three years of launch. Aladdin addresses several of NASA's highest priority science objectives: the origin and evolution of the Martian system (one of two silicate planets with satellites) and the composition and nature of small bodies (the building blocks of the solar system).

The Aladdin mission has been selected as a finalist in both the 1997 and 1999 Discovery competitions based on the high quality of science it would accomplish. The equivalent of Aladdin's Phase A development has been successfully completed, yielding a high degree of technical maturity.

Aladdin uses an innovative flyby sample acquisition method, described in detail in [1], which has been validated experimentally and does not require soft landing or anchoring. An initial phasing orbit at Mars reduces mission propulsion requirements, enabling Aladdin to use proven, low-risk chemical propulsion with good mass margin. This phasing orbit is followed by a five month elliptical mission during which there are redundant opportunities for acquisition of samples and characterization of their geologic context using remote sensing.

The Aladdin mission is a partnership between Brown University, the Johns Hopkins University Applied Physics Laboratory, Lockheed Martin Astronautics, and NASA Johnson Space Center.

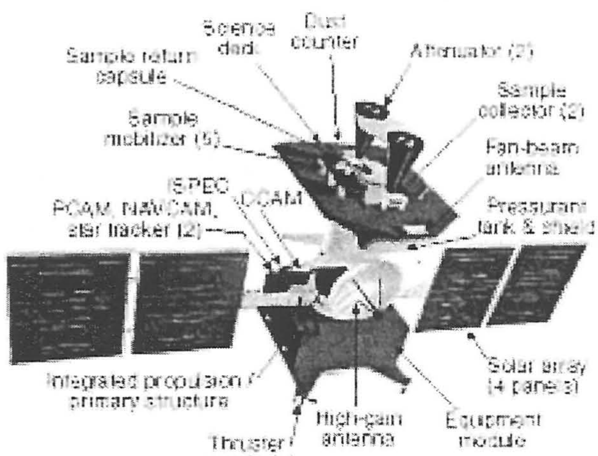


Fig. 1. The Aladdin spacecraft.

Science Background: How (and when) did Mars develop a system of satellites? How are the Martian satellites related to Mars itself? Are they indicative of common processes in the evolution of silicate planets or are they the products of special circumstances? On the one hand, Phobos and Deimos are postulated to be related to primitive outer solar system objects [2, 3]. The geology of each satellite is distinctive and complex [4, 5]. Both satellites have low densities and optical properties resembling primitive asteroids, and they may be the remnants of bodies that delivered organics, water, and other volatiles to the inner solar system. Such primitive bodies are not well represented in meteorite collections, but the proximity of Phobos and Deimos to Mars make them far more accessible with low-cost spacecraft. On the other hand, the two satellites exhibit spectra with a continuum that is similar to that of the Moon and Mercury [5]. This suggests their surface properties might be explained by a space-weathered silicate assemblage resembling bulk material of the terrestrial planets, having a common origin with or derived from Mars.

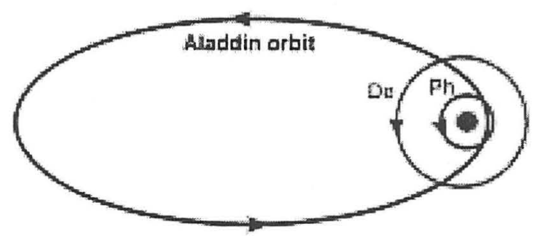


Fig 2. Aladdin's orbit at Mars has repeated encounters with Phobos and Deimos.

Resolving the origins and histories of the two satellites provides insight into early Martian history, but it requires detailed analysis of the mineralogy and chemistry of regolith samples that can only be performed using the advanced analytical capabilities of Earth-based facilities. These measurements will determine whether either moon co-accreted with Mars, is a captured more primitive asteroid or extinct comet, or is derived from Martian basin ejecta. With current analytical technology and expanding experience with IDPs, the amount of sample required to achieve these science objectives can be as small as 3 μg [6]. Aladdin is of course designed to collect far more than this requirement, orders of magnitude more material than the cumulative amount of IDPs analyzed to date. The availability of Aladdin samples in terrestrial laboratories would be a priceless resource for the planetary community, since it would enable questions not yet even conceived to be addressed using techniques not yet developed.

Sample Collection. Aladdin derives its name from its "flying carpet" sample collector, a flexible fiber maze trap. As described in [1] the spacecraft flies through a plume of debris released by small artificial impactors targeted at specific geologic formations on the satellites (two for Phobos, two for Deimos, plus a spare). Regolith particles from the surface are preserved during capture by the exposed carpet collector since both impact and collection velocities are relatively low (~1 km/s). Segments of the carpet are reeled into a sample return capsule (SRC) after each "launch and catch" event, retaining and protecting samples and allowing them to be analyzed separately when returned to Earth. Onboard particle detectors confirm successful interception of each regolith sample. The Aladdin payload dedicated to sample collection includes 5 sample projectile launchers, sample collectors on a spooled carpet, the SRC, and the dust detector.

Remote Sensing: A coordinated series of remote sensing observations obtained before, during, and after sample acquisition place the sample sites in geologic context, and allow inference of global properties from detailed sample analyses. Aladdin's high resolution color imager (CCAM) and visible / near-infrared (0.45-3.6 μm) imaging spectrometer (ISPEC) are used to characterize the moons' surfaces and map geologic units and compositional variations. A specialized monochromatic camera records and locates the artificial impact plumes of regolith (PCAM). A panchromatic navigation camera (NAVCAM) provides optical navigation images for precision targeting.

Radio science experiments will provide significant improvements in the mass estimates, and hence derived density measurements, of both Phobos and Deimos. Knowledge of the densities of these two bodies is expected to be determined to within <10%.

In addition, Aladdin's ISPEC imaging spectrometer is capable of acquiring unique compositional measurements of the Martian surface, with no additional spacecraft or payload capability requirements. The spectral range and resolution of ISPEC are sufficient to discriminate features due to iron-bearing rock forming minerals (crystal field transitions), ferric oxides, and OH-bearing alteration minerals (overtones of vibrational absorptions). The wavelength range includes the regions where fundamental vibrational absorptions of carbonates occur near 3.5 μm. Coupled with these capabilities are a projected SNR that exceeds 200:1 in the visible, 800:1 in the SWIR, and 100:1 near 3 μm. ISPEC design thus provides an excellent opportunity for imaging spectrometer observations of Mars capable of mapping minerals indicative of aqueous environments. A 6000 km periapse orbit allows data to be acquired for Mars with a swath width of ~150 km at 600 m/pixel from equatorial regions to ±50° latitude. Extensive regions of high scientific priority will be mapped at high spatial resolution under high-sun lighting conditions. Aladdin data would provide exceptionally valuable information on Mars' mineralogy that is complementary to, but independent and distinctly different from, data obtained by the Mars Surveyor Program at longer wavelengths.

Table 1. Payload (Sample collection; Remote Sensing)

Instrument	Function
Sample Mobilizer	5 projectile launchers; create plumes of regolith sample from targeted areas on the satellites
Sample Collectors	5 independent carpet segments plus interconnecting leader; collects mobilized regolith.
SRC	Returns samples to Earth
Dust Counter	Detects >1 ng particles; confirms interception of sample
ISPEC Imaging Spectrometer	230 channels, 0.4 - 3.6 μm; characterizes and map mineralogy including Fe and hydrated species, organics
CCAM	characterize moons' geology
NAVCAM	High resolution panchromatic camera; optical navigation, morphology
PCAM	Wide-angle camera; images mobilized regolith plume

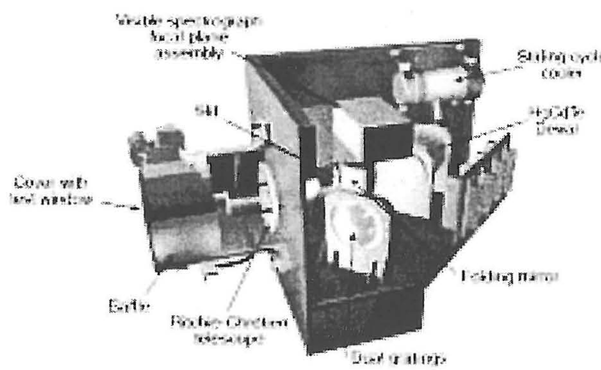


Fig 3. ISPEC, Aladdin's visible to near-infrared imaging spectrometer.

References: [1] Cheng et al. (2000) Concepts and Approaches for Mars Exploration, LPI. [2] Burns J. (1992) in *Mars* (Kieffer et al), 1283. [3] Bell J et al., (1993) in *Resoures of Near-Earth Space*, U AZ, 887. [4] Thomas P. et al. (1992) in *Mars* (Kieffer et al.) 1257. [5] Murchie S. and Erard S (1996) *Icarus*, 123, 63. [6] Zolensky et al. (1998) LPS29, 1716; Zolensky et al., (2000) *MAPS* 35, 9-29.

ATOMIC FORCE MICROSCOPE FOR IMAGING AND SPECTROSCOPY W.T. Pike[1], M. H. Hecht[1], M. S. Anderson[1], T. Akiyama[2], S. Gautsch[2], N.F. de Rooij[2], U. Staufer[2], Ph. Niedermann[3], L. Howald[4], D. Müller[4], A. Tonin[5], H.-R. Hidber[5], [1]Jet Propulsion Laboratory, 4800 Oak Grove Dr. Pasadena, CA 91109-8099, USA, william.t.pike@jpl.nasa.gov[2]Institute of Microtechnology, Univ. of Neuchâtel, Jaquet-Droz 1, 2007 Neuchâtel, Switzerland. [3]CSEM, Jaquet-Droz 1, 2007 Neuchâtel, Switzerland, [4]Nanosurf AG, Austrasse 4, 4410 Liestal, Switzerland, [5]Insitute of Physics, Univ. of Basel, Klingelbergstr. 82 4056 Basel, Switzerland

Introduction: We have developed, built and tested an atomic force microscope (AFM) for extraterrestrial applications incorporating a micromachined tip array to allow for probe replacement. It is part of a microscopy station (Fig.1) originally intended for NASA's 2001 Mars lander to identify the size, distribution, and shape of Martian dust and soil particles. As well as imaging topographically down to nanometer resolution, this instrument can be used to reveal chemical information and perform infrared and Raman spectroscopy at unprecedented resolution.

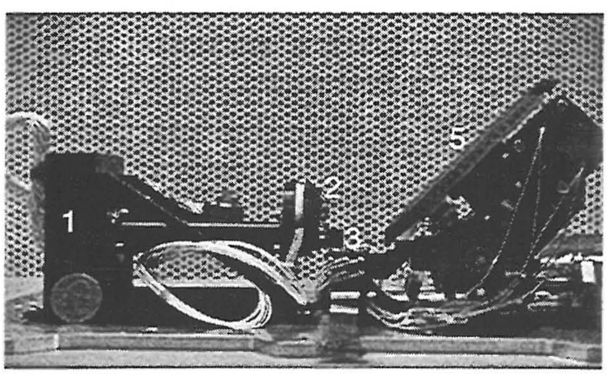


Fig. 1 The microscopy station contains an optical microscope (1), LEDs for illumination (2), an AFM scanner (3) a controller electronics (4) and a sample wheel (5). The robot arm (6) puts soil samples onto different substrates which are then rotated and moved in front of the microscopes. Excess material falls off when turning the sample wheel from the 12 o'clock to the 6o'clock position.

Instrument description: Atomic force microscopy has seen rapid growth in a remarkably short time [1-2]. A tip mounted on a thin cantilever is scanned over the substrate and the interaction between the tip and the substrate is detected by monitoring the deflection of the cantilever. In addition to topography,

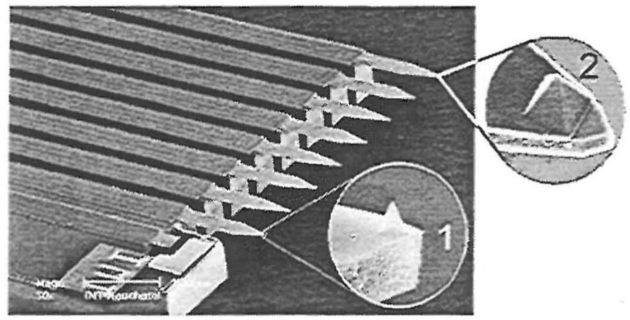


***Figure 2.** SEM picture of the microfabricated AFM chip with support beams etched by DRIE. The insets shows a silicon tip and a CVD molded diamond*

a variety of other signals are available from the AFM. Although most commonly used in terrestrial ambient conditions, the AFM can also operate in liquids and in vacuum over wide temperature ranges.

This AFM developed for planetary applications consists of a single printed-circuit board and a miniaturized scanner. The electronics incorporate radiation-hard components, latch-up protection, and a digital multivoting scheme on critical operation to minimize bit-flip errors. The scanner uses electromagnetic coils rather than the more conventional piezoelectric actuators for scanning in order to reduce volume, power, and voltage requirements. An array of tips has been fabricated using silicon micromachining (fig. 2). Each micromachined array features eight cantilevers for redundancy. Four are equipped with a monolithic silicon tip and four have a diamond tip. The diamond tips are fabricated by chemical vapor deposition into pyramidal silicon molds, and then transferred and affixed to the cantilevers. By mounting this array at an angle only one tip at a time is in the lowest, imaging position. Replacement of the tips and cantilevers, as they are worn down or fouled by material, is effected by cleaving off a complete cantilever and beam using a special tool on the sample wheel.

Cantilever deflection during scanning of the probe is measured by means of a piezoresistive Wheatstone bridge [3]. A reference resistor is incorporated on an ultra-short cantilever for compensating thermal drifts. The noise floor of the complete system, including contributions from electronics, stage and scanner, is about 2 nm.

Imaging: Preliminary AFM experiments using particles in the expected size range showed that

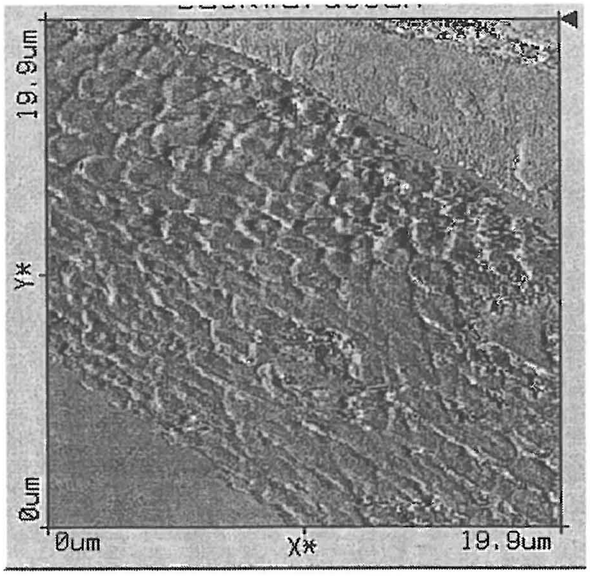


Fig.3: AFM image taken from a fragment of a diatom.

only dynamic mode can be used for imaging. In this mode, the chip is vibrated, exciting the cantilever at its resonance frequency and the tip experiences an interaction with the sample only at its most extended position. The lateral force on the particle and, hence, the chances of sweeping them across the substrate are thus reduced. In the case of the tip array, the excitation is sufficient to overcome the substantial crosstalk between the cantilevers which attenuates the energy injected into the required cantilever.

Figure 3 shows the image of a fragment of a diatom taken in dynamic mode. The image has been digitally differentiated to emphasize the hexagonal structure visible on the surface of the diatom. Phase-contrast imaging, which produces contrast dependent on the viscoelestic properties of the sample, is also possible with this instrument.

Spectroscopy: Using a separate AFM system we have demonstrated the capability of the AFM to produce local spectroscopic information. Both localized infra-red (IR) absorption spectroscopy [4] and Raman spectroscopy are accessible [5].

For IR spectroscopy the AFM deflection signal itself is used as an IR absorption sensor: the absobed IR energy from a chopped incident beam produces a thermal expansion of the sample which can be detected by the AFM tip.

Raman spectroscopy in general produces a weak signal. Using a metallized AFM tip to mediate the signal both enhances and localizes the Raman signal. Figure 4 shows schematically how an AFM tip concentrates the energy from a broad incident beam into Raman scattering. Figure 5 shows two Raman spectra with and without a metallized AFM tip. Both electromagnetic field enhancement and charge-transfer resonance are available mechanisms for the very large

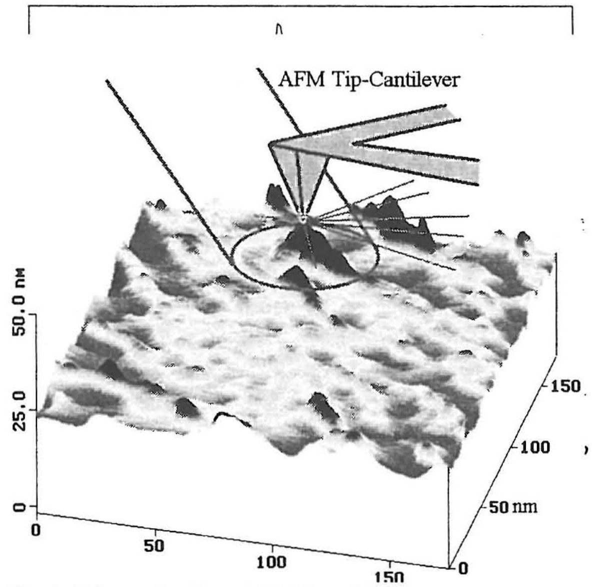


Fig.4: Schematic of ***an AFM-based Raman spectrometer***

gains observed in the Raman signal.

Conclusions: We have demonstrated the feasibility of an AFM for planetary applications. As well as imaging, several chemically imaging and spectroscopy modes are now available at unprecedented resolutions.

References: [1] G. Binning, C. F. Quate, and C. Gerber, Phys. Rev. Lett. 56, 930 (1986). [2] . Dror Sarid, Scanning Force Microscopy, with Applications to Electric, Magnetic, and Atomic Forces, Oxford University Press (1991), and Revised Edition (1994), and Dror Sarid, Exploring Scanning Probe Microsocpy with Mathematica, Wiley (1998). [3] M. Tortonese, R.C. Barett, C.F. Quate Appl. Phys. Lett. 62, 834, (1993) [4]. M. S. Anderson, Appl. Spectr. 54, Number 3, (2000). [5]. M. S. Anderson, Appl. Phy. Lett., (in press, 2000).

ADAPTIVITY AND THE ARCHITECTUIRE FOR A NEW MARS EXPLORATION PROGRAM.

J. D. Pinder[1] and M. I. Richardson[2], [1]RAND, 1700 Main Street, Santa Monica, CA 90407 (pinder@rand.org), [2]Division of Geological and Planetary Sciences, MC 150-21, Caltech, Pasadena, CA 91125 (mir@gps.caltech.edu).

Introduction: In spite of recent failures, the prospects for Mars exploration remain excellent. The motivation for such optimism is, ironically, rooted in cyclical constraints that are unique to this endeavor: steady annual funding of about $200 million; regular launch opportunities every 26 months; 4 to 6 years for the entire spacecraft development process; and 6 to 8 years for the science to unfold through instrument conception and design, and then converge through analysis and publication. These stable cycles create an important opportunity to employ an intelligent exploration strategy that is based on iteractive adaptation, using past triumphs and failures to shape future missions.

This stability, however, also poses a dangerous temptation to take the opposite approach: a static exploration strategy that is focused on a limited let of scientific objectives. Such an approach must, necessarily, rely on a single overarching "best guess" as to exactly which fixed sequence of missions is the most attractive, based on a host of assumptions about the cost, technical risk and potential scientific benefits of the options considered. This approach, however, is fundamentally flawed, even when implemented perfectly, because it does not allow lessons learned over time from both successes and failures to be incorporated into subsequent missions.

Description and Critique of Current Architecture: The Mars Surveyor Program became increasingly driven by a focused goal: that of searching for life or evidence for past life on Mars. In response to this mandate, a development program was implemented to accomplish the return of a sample. This endeavor would require development of a number of untested systems and ultimately require a rather complex chain of operations to accomplish. The development and implementation, driven by these very specific goals, became a facility program with missions defined for all opportunities out to some "distant" date. An assumption in this program was that capabilities could be developed sequentially, and that elements could be proven in a build up to sample return. Another significant assumption was that only sample return endeavors (and any small payload that could "ride along") were worth undertaking.

A major implementation problem for such architecture results from the inconsistency between launch opportunity cycles and spacecraft development cycles. One simply cannot undertake a true sequential (linear, dependent) program within these constraints: there isn't enough time to learn for failures / successes within the development / implementation cycle and retain robustness. A failure in a precursor mission can easily trap a successor mission in the ATLO (post-development, pre-launch) phase where great resources have already been expended on development, but only minor corrective measures can be undertaken. Such a circumstance occurred with the 2001 Lander following the demise of the Mars Polar Lander (MPL). For this reason, *we believe flying common spacecraft buses in subsequent missions to be a high-risk endeavor.* While this may be justified in some extreme circumstances, it can easily be avoided.

The program was forced into application of an architecture inconsistent with the nature of the opportunity due to the belief that only the search for life warranted missions, and that only by returning samples could that goal be met. This singular focus on sample return eliminated all other science, and hence the program's ability to survey the planet. By eliminating flexibility, this focus excluded any ability to follow up on the program's own discoveries or on changing scientific emphasis. More concerning to those interested in the exploration of Mars, this choice of focus set up an "Apolloian" goal that could be checked-off as completed when the first rocks came back from Mars. The danger of advertising sample return as the "be all and end all" of the Mars Surveyor Program is therefore to provide a false "mission accomplished" milestone which attracts cancellation before significant exploration of Mars could be undertaken.

Adaptable Strategies: The stable cycles unique to the current environment for Mars exploration create an opportunity to develop an adaptive architecture that explicitly feeds the technical and scientific outcomes of each mission into the planning process. This sort of flexibility in mission design and selection is especially appealing because it can accommodate the competing scientific objectives of Mars exploration, which often require fundamentally different types of missions. Picking a fixed mission sequence that is focused on one area of interest neglects the others, even if evidence gathered early on indicates that the sole objective is essentially impossible to achieve. By contrast, an adaptive approach that provides rules for selecting future missions using evidence from preceding missions, allows missions that contribute to different objectives to be staggered. In this way they occur in the intervening periods when the results of missions in other areas are being processed and their follow-on missions designed.

It has been shown in other areas of application that when new information is becoming available during the course of an extended endeavor, and multiple options exist for response to the evolving information base, the highest likelihood of success results from an adaptive strategy. In simple terms, while it is possible that notions of how to best accomplish an endeavor arrived at before the commencement will remain the best approach throughout, it is highly unlikely. This is simply a reflection of the fact that as the endeavor proceeds, things are learnt which improve understanding of the focus and implementation of the endeavor. We would be extremely lucky to have correctly guessed the relative importance of all elements which, at the outset, were poorly known. If it is assumed that we will evolve in understanding during the endeavor, then the best strategy becomes one of implementing the most efficient mechanisms for responding to evolving understanding. This requires a sufficiently broad definition of the scope of the endeavor at the outset, and development of mechanisms that foster continual reassessment of current understanding and adaptability in future implementation.

If it is decided that the goals of the exploration include understanding of Martian planetary and climatic evolution, including the central question of whether life evolved, as well as providing a thorough survey of Mars for potential future *exploration, then we strongly urge the implementation of an adaptive approach.*

In essence, we are proposing that the Mars Exploration Program could better spend its energies on defining mechanisms which allow adaptability in mission development than in attempts to define a "long-term architecture" of defined missions, which will likely need to be entirely revised in a few years based on improved understanding of Mars and Mars exploration technologies. While the broad area of science and technology that needs to be accomplished by the program should be clearly defined from the outset, the best strategy of exploration is, in a manner of speaking, to have no strategy except to be as well prepared as possible for the next step ahead and to be fully aware of the available options. Louis Pasteur's quote "chance favors the prepared mind" could easily be adopted as "chance favors the prepared program of exploration".

IMPACT CRATER HYDROTHERMAL NICHES FOR LIFE ON MARS: A QUESTION OF SCALE.
K. O. Pope[1] D. E. Ames[2], S. W. Kieffer[3], and A. C. Ocampo[4], [1]Geo Eco Arc Research, 3220 N Street, NW, #132, Washington, DC 20007, kpope@primenet.com. [2]Geological Survey of Canada, 688-601 Booth St., Ottawa, Ontario, Canada. K1A 0E8. [3]S.W. Kieffer Science Consulting, Inc., P.O. Box 520 Bolton, Ontario, Canada L7E 5T4, [4]Code SD, NASA Headquarters, Washington DC 20546.

Introduction: A major focus in the search for fossil life on Mars is on ancient hydrothermal deposits [1, 2]. Nevertheless, remote sensing efforts have not found mineral assemblages characteristic of hydrothermal activity [3]. Future remote sensing work, including missions with higher spatial resolution, may detect localized hydrothermal deposits, but it is possible that dust mantles will prohibit detection from orbit and lander missions will be required. In anticipation of such missions, it is critical to develop a strategy for selecting potential hydrothermal sites on Mars. Such a strategy is being developed for volcanogenic hydrothermal systems [4], and a similar strategy is needed for impact hydrothermal systems.

Terrestrial Impact Craters: Hydrothermal deposits in terrestrial impact craters <100 km in diameter are limited to fracture and cavity fillings representing minor, short-lived hydrothermal circulation. In contrast, hydrothermal deposits in the ~200 km diameter Sudbury crater in Canada include an extensive basin-wide system and a system focussed along faults that fed a long-lived subaqueous vent complex (carbonate and chert) [5, 6]. The Sudbury vent system is similar to modern deep sea vent systems, known be excellent niches for thermophilic bacteria [7]. Preliminary studies of the ~200 km diameter Chicxulub crater indicate that it too may have had an extensive hydrothermal system [8]. We propose that large craters on Mars hold the most promise for preserving vestiges of extensive, long-lived hydrothermal systems and possibly life.

At Sudbury crater, hydrothermal circulation was driven by the 2.5-km-thick coherent melt sheet (melt mostly free of large unmelted clasts) within the crater. Smaller craters, with significantly thinner impact melt sheets, have minor hydrothermal activity, suggesting direct correlation between melt sheet thickness and the magnitude of the hydrothermal system. Furthermore, data from terrestrial craters indicate that there is an exponential relationship between crater size and coherent melt sheet thickness, and that there may be a size threshold for coherent melt sheet formation (Fig. 1). Most terrestrial craters <35 km in diameter have only mixtures of melt and unmelted clasts. To explain this phenomenon, Cintala and Grieve [9] have suggested that mixing of melt with unmelted clasts is a function of the ratio of melt volume/crater volume. Initially the melt is smeared on the bottom of the crater, and when the melt volume/crater volume is large, the mixed zone is a small fraction of the melt.

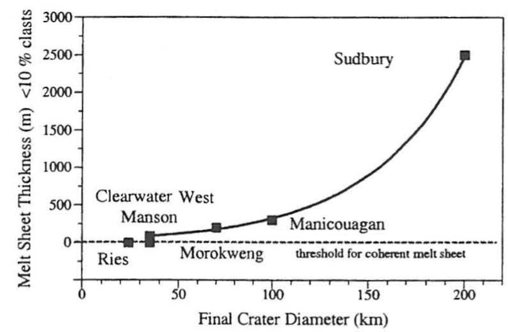


Figure 1. Melt sheet thickness and crater diameter.

When the melt volume/crater volume is small, erosional mixing of melt and clasts results in little to no clast-free melt. This is important because the incorporation of unmelted clasts in the melt can cool it quickly, greatly reducing the longevity of the hydrothermal system that develops.

Scaling for Mars. Before beginning the search for Martian analogues of the Sudbury Crater we must consider several aspects of crater formation that are gravity dependent, since Mars has about 1/3 the gravity of Earth. Due to this gravity difference, craters on Mars are about 1.24 times larger than craters on Earth (given impactors with the same mass and velocity). Another factor is projectile velocity. Typical velocities of asteroids and comets that impact Mars are ~ 19 km/s and 42 km/s, vs. ~25 km/s and 53 km/s on Earth [10]. Thus, for average craters with similar impact energies on Earth and Mars, Martian craters were formed by lower velocity (greater mass) projectiles. This is important because the mass of impact melt generated scales with V^2. When this relationship is coupled with the one above relating to larger craters on Mars, comparisons between crater size and melt can be made using the following equation [11]:

$$\frac{Mm}{Md} = 1.6 \times 10^{-7}(gDt)^{0.83}Vi^{0.33}$$

IMPACT CRATER HYDROTHERMAL NICHES ON MARS: K.O. Pope, D.E. Ames, S.W. Kieffer, and A.C. Ocampo

where Mm is the mass of impact melt, Md is the mass of rock displaced from the crater cavity, Dt is transient crater diameter (~0.5-0.6 final diameter), g is gravity, and Vi is the impact velocity.

We combined the empirical data on coherent melt thickness and gravity scaling to predict which craters on Mars are likely to have melt sheets capable of driving a long-lived hydrothermal system. The threshold final crater diameter for the formation of a coherent melt sheet on Earth is ~ 35 km, which corresponds with a Mm/Md = 0.11 (asteroid impact). Such a Mm/Md on Mars corresponds with a final crater diameter ~ 100 km (Fig. 1).

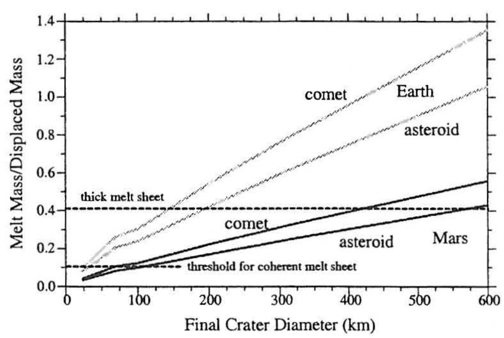


Figure 2. Scaling of Mm/Md for Earth and Mars.

Terrestrial craters with a thick coherent melt sheet such as Sudbury have a Mm/Md = 0.42, which on Mars corresponds with a final crater diameter of ~ 600 km (asteroid impact) or 440 km (comet impact).

Conclusions. We conclude that only very large craters on Mars have a high potential for developing long-lived hydrothermal systems. Martian craters < 100 km in diameter can probably be ruled out completely because they would produce melt mixed with a large number of clasts and therefore cool quickly. Craters < 200 km in diameter are tenuous, but may develop coherent melt sheets a few hundred meters thick (analogous to Manicouagan on Earth), which could drive a large, albeit short-lived, hydrothermal system. Martian craters capable of forming a Sudbury-like hydrothermal vent system fall in the 400 – 600 km size range. Such craters are rare on Mars (excluding ancient basins formed during the heavy bombardment period), which greatly limits the search. Candidates include Huygens (460 km), Schiaparelli (470 km) (Fig. 3), and Cassini (430 km).

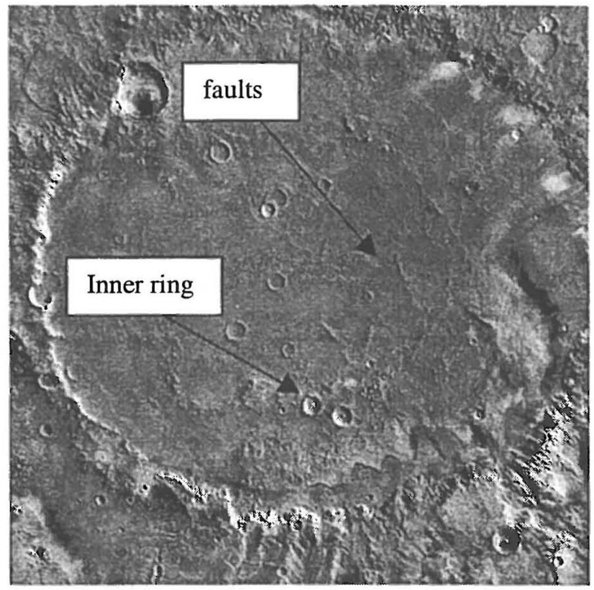


Figure 3. Schiaparelli crater, Mars (470 km diameter). By anaolgy to Sudbury, hydrothermal depoists may be found associated with faults inside the inner ring.

References: [1] Farmer, J. D., 1996, In, *Evolution of Hydrothermal Ecosystems on Earth (and Mars?)*, edited by G. Bock and J. Goode, Wiley, Chichester (Ciba Foundation Symposium 202) p. 273-299. [2] Farmer, J., 1998. *J. Geophys. Res* 103: 28,457-28,461. [3] Christensen, P.R., et al., 2000. *J. Geophys. Res.* 105: 9623-9642. [4] Dohm, J.M., Baker, V.R., Anderson, R.C., Scott, D.H., Rice Jr., J.W. and Hare, T.M., 2000. *Lunar Planet. Sci.* XXXI, CD abstract 1613. [5] Ames, D.E., 1999. Geology and regional hydrothermal alteration of the crater-fill Onaping Formation: Association with Zn-Pb-Cu mineralization, Sudbury Structure, Canada. Unpub. Ph.D. thesis, Carleton University, 10 maps, CD-ROM, 460 p. [6] Ames, D.E., Bleeker, W., Heather, K.B., and Wodicka, N., 1997. Geol. Assoc. Canada – Mineral. Asssoc. Canada, Joint Annual Meeting Ottawa '97, Field Trip Guidebook, 133 p. [7] Karl, D.M., ed., 1995. *The Microbiology of Deep-Sea Hydrothermal Vents*, CRC Press, Inc., Boca Raton, Florida, 299 p. [8] Pilkington, M., and Hildebrand, A.R., 2000, Three-dimensional magnetic imaging of the Chicxulub crater, *Lunar Planet. Sci.* XXXI, CD abstract 1190. [9] Cintala, M.J., and R.A.F. Grieve, 1994. *GSA Spec. Pap.* 293, pp. 51-59. [10] BVSP (Basaltic Volcanism Study Project), 1981. *Basaltic Volcanism on the Terrestrial Planets*, New York, Pergamon Press, 1286 p. [11] Melosh, H.J., 1989. *Impact Cratering*, New York: Oxford Univ. Press, 245 p.

Sample Acquisition Systems for Sampling the Surface Down To 10 Meters Below the Surface for Mars Exploration. S. Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com), T. M. Myrick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, myrick@hbrobotics.com), S.P. Gorevan, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, gorevan@hbrobotics.com), K.Y. Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), S. Singh, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sase@hbrobotics.com), J. Ji , (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, chunlei@hbrobotics.com), C. Batting, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, cbatting@hbrobotics.com)

Introduction: Mars missions may benefit from sample acquisition systems under development that are capable of acquiring samples from the surface, from a few centimeters below the surface, from 1 meter below the surface and from 10 meters or more below the surface.

The SATM: The Sample Acquisition and Transfer Mechanism (SATM)[1] is a highly developed sampling tool that features interfaces with in-situ science instruments and sample return containers.

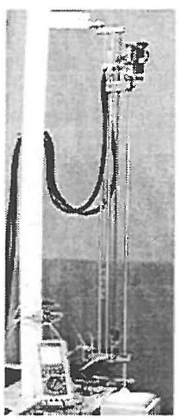


Figure 1: The 1 Meter Deep Drilling SATM Prototype

A prototype SATM has been developed and successfully tested at Honeybee Robotics to demonstrate the performance requirements necessary to meet the ST/4 Champollion mission goals., many of which could be applicable to a Mars sampling mission. The SATM has been designed to:

- acquire surface samples, samples at 20 centimeters below the surface and samples at 1 meter (or more) below the surface, without cross contamination. To accommodate the different sample volume requirements by each instrument, the SATM is also designed with a sample chamber that can be infinitely adjusted from 0.1 cc to 1.0 cc. A newer version of SATM is being planned for development in FY01 in collaboration with the JPL Exploration Technology program, where the sample volume will be increased to a maximum of 50.0 cc. This new SATM will also be capable of taking a core sample.
- transport and transfer samples to a microscope/IR spectrometer, chemical analysis ovens, and a sample return container. For the microscope, the SATM features a sapphire window through which the samples in the chamber can be presented for analysis.

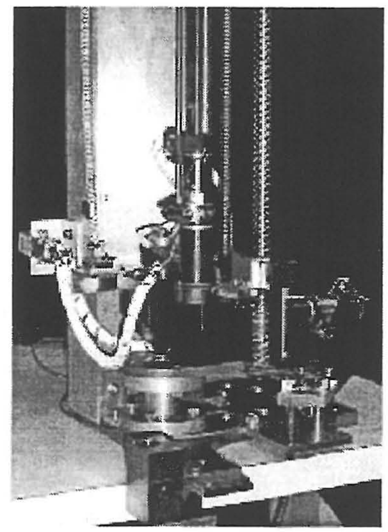


Figure 2: SATM Interface with OVEN

Deep Drilling Sampler: a Deep Drilling Sampler (DDS) for use on Mars has been initiated this year by Honeybee Robotics for the NASA PIDDP program. This system will be capable of acquiring and manipulating a stratigraphy maintained sample from 10 meters deep below the surface of Mars. The DDS technology will be a scalable, low mass (10-25 kg), small form factor (58cm x 37cm x 13 cm), deep drilling (5 m in the PIDDP implementation but easily scalable), core sampling robotic device. The DDS will be capable of supporting both in situ analyses of collected samples, as well as transferring of samples to sample return containers. The DDS samples can be taken from many depth levels and will always have its stratigraphy maintained.

Leveraging Mature Sample Acquisition Developments: The DDS is already quite developed as the basic drilling technology closely leverages the highly developed SATM.. Additionally the method of acquiring the sample, with its stratigraphy maintained is closely related to the method first advanced by the Athena Mini-Corer, which is nearly flight ready. [1]

The DDS Sample Capture subsystem: The sample capture subsystem of the DDS is the mechanism capable of acquiring a stratigraphy maintained sample. During the development of the Mars Athena Mini-Corer, technology was developed that allowed core samples to be taken from rocks. The DDS will enhance this capability to enable the acquisition of short cores down to the 10-meter range. Furthermore the technology will be refined to allow a more complete sealing of the acquired sample so that unconsolidated samples may be acquired. Under the PIDDP effort, a breadboard will be developed to achieve these goals, by putting motors needed for actuation inside the lead drill string, and by enhancing the nested tube geometry to prevent loose grains from escaping the sample chamber. The motors inside this lead drill string provide a method of moving a center-drill/pushrod device used for drilling-sample ejection and for rotating the shear tube which shears the sampled core from the base rock and captures it inside the sample chamber. A key goal is to develop this technology into as small a form factor (small diameter drill string) as possible, while still maintaining high reliability and the strength needed to shear cores from strong rock.

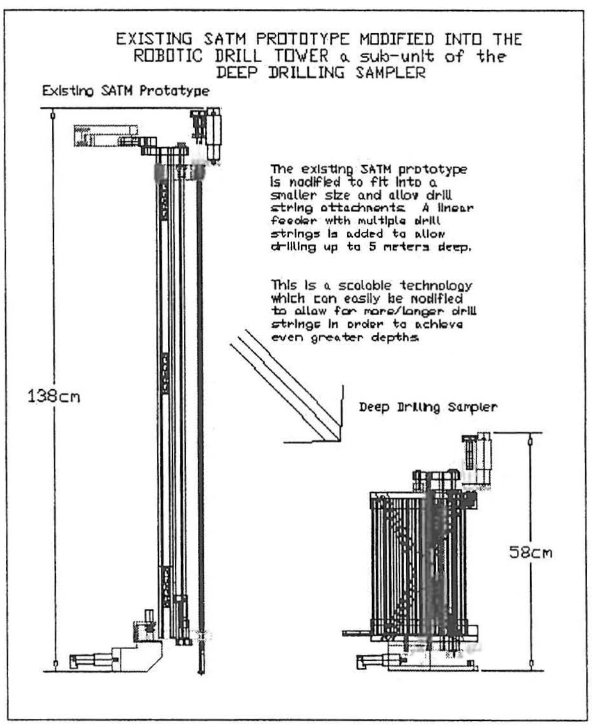


Figure 3: A copy of the existing Champollion/ST4 SATM prototype will be modified into a Robotic Drill Tower capable of accepting drill string segments.

To Reach 10 Meters Below the Surface: Deep drilling will be achieved by using multiple drill strings (segments) which can be autonomously attached to one another during drilling, and then detached during extraction. Instead of a tall drill tower with a single long drill string attached, a much smaller device will be created which will be able to use many smaller drill string segments. This segmented approach allows deep drilling to take place from a small, low mass device. . To enable this, a drill string feeder is being developed to present the individual drill strings to a robotic drill tower.

Miniature Samplers: Additional miniature sample acquisition systems have been developed by Honeybee Robotics under a NASA Phase I SBIR award.[2] They include:

- A miniature penetrator that is ballistically fired from a rover or lander. The miniature penetrator is tethered to a rover or a lander. Retraction of the penetrator activates a sampling mechanism that captures a sample at the furthest depth penetrated.
- A miniature inchworm sampling system that is deployed from a rover or a lander. This system employees an inchworm locomotion technique for subsurface travel.
- A telescoping sampling system is highly compact in the stowed condition but extends to the surface to acquire stratigraphy maintained cores.

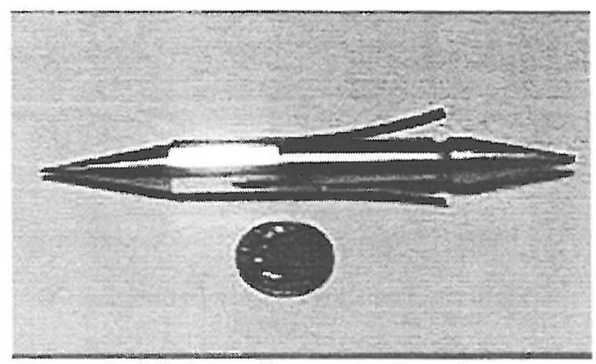


Figure 4: Miniature Penetrator Sample Acquisition System

References: [1]S.Gorevan,S.Rafeek, The SATM for Champollion, Advanced Developments in Space Robotics AIAA Tech. Forum, University of Wisconsin, August, 1996. S.Gorevan,T.Myrick, Shaheed Rafeek.

[2] Rover Mounted Sample Acquisition Systems, Proceedings of Interntl. Rover Conference, The Planetary Society, Santa Monica, CA, March 1997.

Mars Balloon based Touch and Go Surface Sampler (TAGSS) – S. Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com), S. Stroescu, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sergiu@hbrobotics.com), K. Y. Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), S. Sadick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sadick@hbrobotics.com), P. W. Bartlett, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, bartlett@hbrobotics.com), K. R. Davis, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, krdavis@hbrobotics.com) and M. A. Ummy, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, ummy@hbrobotics.com).

Introduction

The Touch and Go Surface Sampler (TAGSS) is a new class of planetary body sample acquisition tool that can be used for Mars surface sampling. TAGSS in its basic configuration consists of a high speed sampling head attached to the end of a flexible shaft. The sampling head consists of counter rotating cutters that rotates at speeds of 3000 to 15000 RPM. The attractive feature of this "touch and go" type sampler is that there are no requirements for a lander.

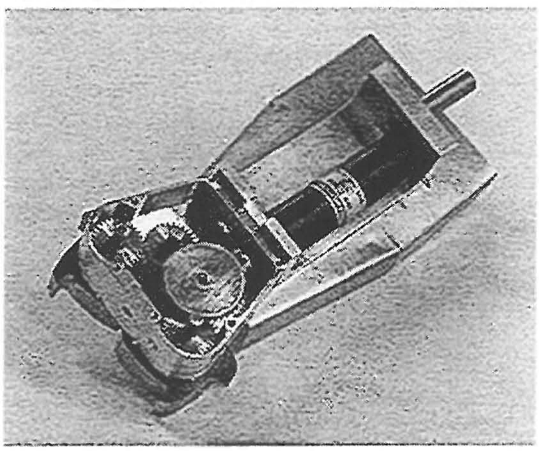


Figure 1: Phase I TAGSS Sample Head

Operation Sequence

Operationally, a hopping balloon craft with a TAGSS attached will descend to a selected surface site in a controlled manner with a predetermined surface relative speed. At a given height above the surface, the TAGSS will be deployed and energized. A leading contact sensor will give positive indication of sampling start time as the balloon continues its slow descent. The flex shaft (1.5 meters or longer) attached to the TAGSS will provide the required preload for sampling as the balloon continues its descent for an additional 1 to 2 seconds after the contact sensor have been triggered. The samples can either be collected and captured at the tool head or directly ejected through the Mars atmosphere towards onboard sample analyzer apertures located at the bottom of the balloon

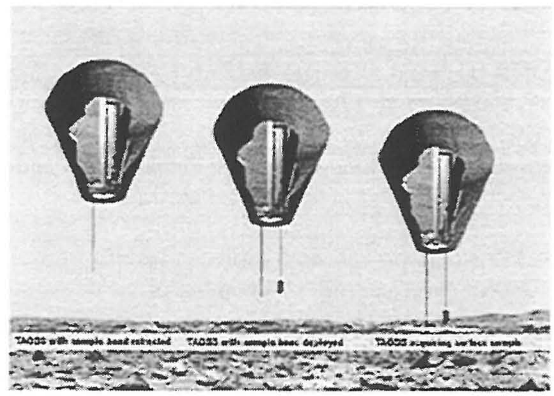


Figure 2: "Touch and Go" Sampling on Mars

payload/instrument bay. The high cutting-bit speed ensures that the ejected samples have enough momentum to reach the sample analyzers. In a controlled capture, the samples are contained in the head of the TAGSS and will be retracted into the payload/instrument bay of the balloon as the craft ascend back to a safe height.

Development Effort

A just completed NASA SBIR Phase I effort to test the validity of TAGSS as a surface sampler has yielded very positive results. Additional observation from the Phase I results show that TAGSS can be used for more than just surface sampling. The results gave strong evidence to suggest that TAGSS can be mechanically and functionally enhanced to penetrate the surface and obtain subsurface samples, possibly up to 1 meter in loose or low compressive strength material.

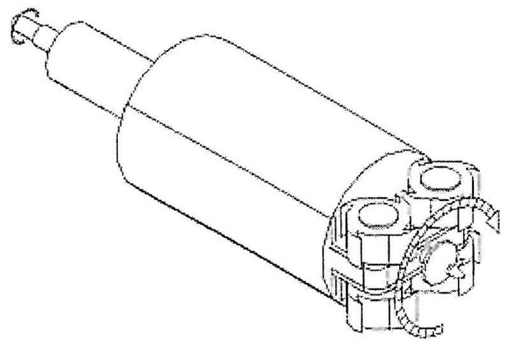


Figure 3: Proposed Phase II TAGSS Sample Head

Honeybee Robotics has submitted a Phase II SBIR proposal to secure funding to continue the development of TAGSS to add several mission critical elements to the sampling system, such as deeper penetration, automated deployment and controls and sample transfer capabilities.

A Mars balloon based mission can benefit from a TAGSS class sampler in a number of ways:

(1) In the "touch and go" mode, there are no requirements for a landing system. In past missions, the reliability of landing systems has resulted or contributed to failures resulting in the loss of entire payloads.

(2) TAGSS is better suited for unknown topography. The flexible shaft attached to the sampling head of TAGSS allows it to conform to the various sloped, hill, and depression contours of a Mars terrain.

(3) Samples can be obtained from multiple sites. A balloon based mission on Mars can "hop" from site to site taking samples for in-situ analysis or even for sample return.

(4) Reduced mission cost. With no requirements for a landing system or an orbiter, the cost of a TAGSS balloon mission to Mars will be greatly reduced.

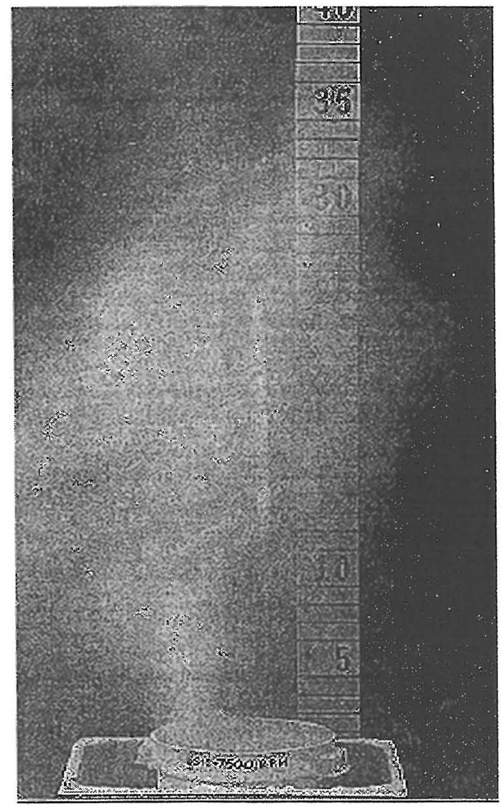


Figure 4: Sample Test Demonstration for Phase I – Surface Material Is Ejected with TAGSS Breadboard

References: NASA SBIR Phase I – Contract No. NAS2 – 00019, Dec 9, 1999.

THE NEED FOR HIGH-RESOLUTION CRUSTAL MAGNETIC FIELD DATA ON MARS. C. A. Raymond[1], C. T. Russell[2], M. E. Purucker[3] and S. E. Smrekar[1], [1]Jet Propulsion Laboratory/Caltech (MS 183-501, 4800 Oak Grove Dr., Pasadena, CA 91109; craymond@jpl.nasa.gov; ssmrekar@jpl.nasa.gov), [2]IGPP/UCLA (Los Angeles, CA 90095; ctrussell@igpp.ucla.edu), [3]Raytheon ITSS at NASA/GSFC (Greenbelt, MD 20771; purucker@geomag.gsfc.nasa.gov)

Introduction: Magnetometer observations from the Mars Global Surveyor spacecraft (MAG/ER on MGS) have confirmed that Mars does not presently have an internally-generated dipole magnetic field, and have also revealed intense remanent magnetism in the Martian crust [1,2]. The remanent magnetic anomalies, most prevalent in the southern highlands region, are a record of the past history of the internal Mars dipole field. The MAG/ER data constitute a valuable data set for constraining the early thermal evolution of Mars and the history of the planetary magnetic field. However, the data lack the resolution needed to draw definite conclusions regarding the time history of the field. High-resolution magnetometer observations, obtained at low-altitude, are needed to complement and extend the MGS/ER data set and allow a definitive time history of the internal Mars dynamo to be constructed

Magnetic Fields and Life: The question of the chronology of the Martian magnetic field not only concerns the early thermal evolution and differentiation of the planet which are important topics by themselves, but it also is critical for understanding the stability of water in Mars' atmosphere and the radiation environment of the planet which both have significant impact on the emergence and sustainability of life on Mars. The shielding planetary magnetic field would have protected the atmosphere from erosion by the solar wind, and would have protected the surface from bombardment by cosmic rays.

The Need for Low-Altitude Magnetic Data: The MGS MAG/ER data are limited in spatial resolution to wavelengths above approximately 200 km at the periapsies. Resolution at higher altitudes is worse. At this resolution, it is predictable that of most of the features seen in the altitude- and spatially-binned data set that has been released [3] are actually low-pass filtered renderings of the true spatial anomaly pattern. It is difficult to assess the sources, and thus the causative processes that created the magnetized crust when the true scales are poorly understood. An example is the apparently non-magnetic region of the southern highlands surrounding the Hellas and Argyre basins, thought to have been demagnetized by the megaimpacts that created the basins[1]. This region may actually be magnetized at a very fine scale, which is not detectable at the spacecraft altitude, or it could be coherently magnetized (possess no magnetic contrasts). A sampling of the near-surface magnetic field is required to determine if the crust is indeed nonmagnetic before we can understand why it is so. The northern lowlands is another region that might possess a high frequency, low-amplitude anomaly pattern that defies detection at spacecraft altitudes. Until the true distribution of the remanent sources is known, the evaluation of the field history will be incomplete.

Measurement Requirements for Low-Altitude Magnetic Field Data: In order the characterize the higher order energy in the magnetic field power spectrum (the high-frequency spatial pattern), the following requirements should be met:

Altitude. A minimum altitude of 50 km is needed. The fields of near-surface sources drop off rapidly, and the altitude filter will smear very high frequency patterns. An altitude below 20 km should reveal nearly all the details of the pattern.

Coverage. At a minimum, profiles crossing several major magnetic contrasts (anomalies) as seen in the MGS data are needed. Ideally, the profiles would cross several 'stripes' in the Terrae Sirenum and Cimmeria regions [2], as well as cross the apparently nonmagnetic regions of the southern hemisphere, and over the boundary between the magnetized and non-magnetized regions. Profiles crossing the dichotomy boundary would also be valuable, and over the northern lowlands and the Tharsis Rise. Only a few profiles would be sufficient to reveal the frequency distribution and thus increase the value of the MGS data considerably. A program of targeted observations spanning multiple missions would likely be needed to reach all the critical areas.

Magnetometer. An accuracy around 1 nT scalar should be met as a minimum requirement for fields up to several thousand nT. The dynamic range required is at least 50,000 nT, and ideally 100,000 nT. Vector measurements will help to identify ionospheric noise and details of the source dimensions, but most information will be derived from the scalar or radial component data.

Low-Altitude Mobile Platforms. There are several choices for obtaining the low-altitude data argued for. Orbiters, including highly elliptical orbits, cannot deliver the altitudes needed. Rovers and surface systems are too limited in mobility and too close to the surface to be effective. The best candidates are airplanes, airships and balloon platforms. While an airplane would provide a targeting capability, the restricted range would make it a less effective means to obtain the data, unless a specific target was sought. Airships and balloons offer the greatest opportunity to collect significant data sets at altitudes below 10 km. Further work is needed to better define the relative advantages and disadvantages of each of these platforms relative to the scientific payoff.

References: [1] Acuna, M. H. and 12 authors (1999) *Science*, *284*, 790-793. [2] Connerney, J. E. C. and 9 authors (1999) *Science*, *284*, 794-798. [3] Purucker, M., D. Ravat, H. Frey, C. Voorhies, T. Sabaka, and M. Acuna (2000) Geophys. Res. Lett, in press.

MARS ANALOG FIELD TRAINING OF ASTRONAUTS.

James W. Rice, Jr., Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, USA; (jrice@lpl.arizona.edu).

Introduction

The latest high resolution MOC images reveal that Mars has had a very complex and rich geological history. This new and exciting discovery is perhaps best illustrated in the imagery which shows abundant layering in the walls of canyons, channels, craters, and scarps. Clearly, these types of sites can only be fully investigated and properly sampled by astronauts. Additionally, any thorough search for extinct and or extant life will have to be carried out by astronauts. This will involve great surface mobility, flexibility, deep subsurface drilling, and intelligence in the field; activities best accomplished by astronauts.

Some of the ideas expressed in this paper are from being a member of the joint NASA / LPI sponsored workshop on Mars Field Geology, Biology, and Paleontology held November, 1998 in Houston [1]. The purpose of this workshop was to formulate recommendations that would ultimately contribute to NASA policy regarding human exploration of Mars. Participants included world class field geologists, geochemists, biologists, paleontologists, Apollo astronauts who explored the Moon, the scientists who trained them, Space Shuttle and future Space Station astronauts, NASA/JSC EVA Office, and NASA mission planners.

The best geologist is the one who sees the most rocks

The Apollo astronauts received fairly extensive geological field training from numerous field geologists at the U.S. Geological Survey, various Universities, and NASA. These field exercises proved to be invaluable and contributed greatly to the achievement of all lunar surface science objectives (including intelligent sample acquisition and documentation). Moreover, these field based exercises were also useful in sharpening the skills and interaction of astronauts and the ground science teams.

Mars analog studies and geological field training exercises will be even more crucial in the manned exploration of Mars because of its rich and complex geological history (perhaps even biological history), unlike the Moon. This will present new and exciting challenges to the manned exploration of both the surface and subsurface of Mars. Astronauts will be able to carry out the proper field investigations for correct geological context of the landing site as well as the surrounding environs, conduct precision landings, maximize surface mobility, and also perform intelligent sample acquisition and interpretation.

When should the Mars analog field training program begin? It is not too early to begin preparing for the first Mars expedition and several reasons are mentioned below: (1) The art and skill of Field Geology can only be learned by being in the field. (2) Additionally, Field Geology is a cumulative science, meaning the more experience you get the better you get. (3) The links should be forged between the science, operations, and astronaut communities now because it will take time to achieve the collective experience level necessary for the proper interaction of these communities. This will prove invaluable in supporting and controlling a multi-year Mars expedition [2].

Field geology is a slow process. If what is found is not what the working hypothesis suggested should be there, then this new information needs to be factored in to modify the working hypothesis so that it will predict what will be found at the next stop. If these predictions come true, then confidence in that working hypothesis increases. Eventually, after all data is synthesized into the traverse, a 'final' geological evolution of the site will be proposed [3].

Field geology in a space suit is an even slower process. The field geologist typically will recon a site, take a few photographs, record his observations in a notebook, break some rocks open, inspect each with his hand lens to determine the texture, structures, and mineralogy of the sample so that he can give it the correct name, and collect those samples that seem diagnostic of the locality as well as any 'odd' samples. In a space suit most of these tasks will take longer or will be impossible to do (write notes, for example) so that these tasks will need to be accomplished by other means. Therefore, it is imperative that training begin sooner rather than later.

Astronauts attending the Workshop stated that experience shows it is best to select a crew weighted toward the primary scientific skills for the extensive surface mission, and cross-train them to accomplish the spacecraft systems, operations, and maintenance functions [2]. Apollo and Space Shuttle experience indicates that scientists can successfully acquire the essential mission operations skills in just a few years of spaceflight training, while the reverse process of training pilots and technicians for a primary science role will not work on a similar time scale. Geologist and Apollo 17 astronaut Jack Schmitt's estimate is that during Apollo, the scientists had acquired 75% of the operations skills of the pilots in the program, while the latter had attained 25% of the field geology skills typical of active field geologists. Our consensus was that successful cross-training can be accomplished over a period of about 10 years. That's about the time scale for development of expert operations skills via actual spaceflight experience on shuttle and station, experience that is a likely prerequisite for Mars mission candidates [2].

The author has been a geological field team member on numerous national and multinational expeditions of short and long duration (up to 6 months) to Antarctica, Devon Island in the Canadian High Arctic, Iceland, Paleolake Bonneville in Utah, Channeled Scabland in Washington, and numerous other sites in the American southwest and Mexico. It will be useful to train the crews in both modern and ancient processes / environments. The merit of studying an active flood or volcano provides valuable insight into both processes and landform development. The following sites are excellent Mars analogs and will be discussed in more detail below. This list is not meant to be complete and final but rather a starting point of where to begin the process of Mars analog field training of astronauts in the near future.

Antarctica: The ice free desert regions of Antarctica are no doubt the best Mars analogs in terms of mean annual temperature, aridity, winds, and remoteness. These regions also contain relevant Martian analogs such as ancient lake deposits, deltas, sand dunes, cinder cones, and periglacial processes and landforms. Glacial landforms have been postulated for Mars and these regions obviously contain glacial landforms. The field investigation of Antarctic microbial life habitats (i.e., endoliths, cryptoendoliths, chasma-liths) would also provide useful training for Mars missions.

Iceland: Provides active and ancient volcano – ice interactions, hydrothermal sites, jökulhlaups (active and ancient catastrophic floods), periglacial, and glacial processes and landforms.

Devon Island: A 20 mya (20 km diam) impact crater in a periglacial environment is the key landform. This crater also once contained a lake.

Channeled Scabland: Largest paleoflood in the world. Ideal site for studying large scale catastrophic flood features.

Paleolake Bonneville: One of the largest paleolakes in the world with excellent preservation of shoreline morphology and lake sediments, and also contains evidence of volcanic eruption (Pavant Butte) into lake.

Meteor Crater: Impact crater used in training of Apollo astronauts.

Grand Canyon: Small scale analog to Valles Marineris, useful for stratigraphic studies.

Death Valley: Numerous landforms (volcanoes, playas, arroyos, debris flows, dunes, alluvial fans, lake sediments, spring deposits, evaporite deposits, fault scarps).

Yellowstone: Hydrothermal processes.

Atacama Desert: Extremely high altitude arid desert with playas, channels, debris flows, small impact crater.

Hawaii: Active volcanoes.

The establishment of an ongoing program of scientific field exercises geared toward Mars surface exploration will allow astronauts to gain valuable experience in managing a field research program, practice on site decision making, cope with changing research strategies, and to develop the cross training necessary for a successful expedition [2]. Astronauts participating in Mars analog field work should be equipped with the same tools and equipment that they will use on Mars in order to practice techniques and to allow the crew members to become familiar with the capabilities and limits of their equipment. These analog field expeditions will also blend real scientific field work by the astronauts with a ground support team. These activities should also have built in transmission delays and will foster the required interaction between the field team and ground support teams. It should be noted that because of time delays the astronauts will mostly be "on their own". Finally, these analog field expeditions should be geared toward accomplishing real scientific work not merely observation.

References: [1] Budden, N.A., 1999, Mars Field Geology, Biology, and Paleontology Workshop: Summary and Recommendations, LPI Contrib. No. 968, 80p. [2] Jones, T., et al., 1999, Crew skills and training, in Mars Field Geology, Biology, and Paleontology Workshop: Summary and Recommendations, N.A. Budden ed., LPI Contrib. No. 968, p. 25-30. [3] Muehlberger, W.R., et al., 1999, Approach to Mars field geology, in Mars Field Geology, Biology, and Paleontology Workshop: Summary and Recommendations, N.A. Budden ed., LPI Contrib. No. 968, p. 5-13.

THE "WHY" AND THE "WHAT": THE SCIENCE FOCUS OF THE MARS EXPLORATION PROGRAM.
M. I. Richardson[1] and E. J. Gaidos[2], [1]Division of Geological and Planetary Sciences, MC 150-21, California Institute of Technology, Pasadena, CA 91125 (mir@gps.caltech.edu; gaidos@gps.caltech.edu).

Introduction: The high-level scientific goals and themes of the Mars Exploration Program place important requirements on the nature and architecture of the program. Choices at this level impact not only the particular sequence of missions to be flown, but also the program's saleability, the extent to which the planetary science community is engaged in the program, and the ultimate value of the program both to our understanding of Mars and as a survey tool for deciding whether humans should venture there. We briefly review the history of scientific interest in Mars, through to the inception of the Mars Surveyor Program (MSP). While the MSP began as a relatively broad-based investigation of Mars, the excitement surrounding the "discovery" of life in the Martian meteorite ALH 84001 redirected the program onto a pathway almost singularly focused on searching for fossil (or even extent) life in returned samples. We support the notion that the question of life is the single most important theme in Martian exploration. However, we argue that the approach that has evolved in the MSP - and would govern missions to be flown beyond 2001 - is overly focused. This threatens the utility of the program as a means of understanding the cause and context of life's absence or presence. The rush to a yes-or-no answer on life has also placed technical strain on the program, will ultimately disenfranchise a significant fraction of the scientific community, and will seriously limit the ability of the program to "survey" the planet for future exploration.

Interest in Mars Through to Viking: Historically, interest in Mars has centered on perceived Earth-like conditions and the potential for life. This interest can be traced back at least as far the 1698 publication of Kosmotheros, in which the Dutch astronomer Christian Huygens speculated about life on Mars and other worlds. Later astronomers discovered polar caps, a length of day and axial tilt like those of the Earth, a thin atmosphere, clouds, and variations in surface features resembling seasonal changes. Primitive Martian plant life was still considered possible until 1964 when the Mariner spacecraft began reaching the planet and revealed it to be a desolate, dry, and intensely cold world. Mars presented a very "lunar" visage to the earlier Mariners, but excitement about life, albeit microscopic, resurfaced after Mariner 9 provided ample evidence for liquid water at some point in Martian history. However, stock in Mars as a habitable planet fell to a new low in 1976 when twin Viking landers specially designed to look for life were sent to two widely separated locations on Mars Instead of life, they found a soil so highly oxidizing that it is lethal to all life as we know it and would likely obliterate evidence of that life.

The Mars Surveyor Program. Despite the disappointments, the Mariner and Viking spacecraft made fantastic discoveries, including extinct volcanoes, valleys and channels apparently carved by running water, and evidence for ground ice and a thicker early atmosphere. A new paradigm arose of Mars as a planet with a warmer, wetter, and more active past - perhaps similar to the Earth when it hosted primitive life, and motivated ideas of searching for microfossils or hardy subsurface life like that found in "extreme" environments on Earth. The question of life was now set firmly within the context of planetary evolution and climate evolution. The discoveries provided an image of a world far more Earth-like than any other in the solar system, with an active climate system which likely varied significantly through the planet's history. Successive missions were developed to examine the planet and its environment in greater detail. The establishment of the Mars Surveyor Program (MSP) followed the failure of the Mars Observer (MO) and the cancellation of the Mars Environmental Survey missions, but initially retained their inclusive goals. However, three years after the advent of MSP, the claim of fossil life in the Martian meteorite ALH 84001 generated tremendous excitement and controversy and the search for life once again shifted to dominate Mars exploration. This altered focus provided impetuous for ambitious plans to return samples from the surface of Mars in 2005 in hopes of finding life in them. The decision to return samples so soon influenced preceding missions: the primary payload for the 2001 lander was chosen to be a rover that would serve in later missions as a vehicle to find and retrieve samples. On the 2001 orbiter, the reflight of the MO gamma ray spectrometer was to be accompanied by an instrument selected primarily in terms of sample-return landing-site selection. The effort required to develop a sample return vehicle demanded that orbiter science be eliminated after the 2001 mission. Further, instruments on landers were either to address sample return-related issues, or make measurements deemed essential for future human missions to Mars. The exploration program would thereafter consist of sample return missions into the second decade of the 21st century.

The Search for Life in Context. The question of life on Mars is a profound one, but a single-minded focus on a yes or no answer is an intellectually impoverishing reduction of the study of planetary habitability. The search for life is but one of a suite of many questions which provide both cause and context. Over the course of three decades of exploration, we have come to appreciate Mars as a complex world shaped by volcanism, wind, ice, and, at least occasionally, the flow of liquid water. It is a planet whose evolutionary path has diverged from the Earth's for reasons that are poorly understood but are profound for life. That the non-science public appreciates this is evidenced by the enormous interest in the pictures from the Mars pathfinder that revealed a landscape far more lifeless than any place on Earth.

Using Sample Return to Look for Life: Sample return as a scientific experiment is poorly posed. There is a straightforward reason for this. At it's heart is the testable hypothesis that life at one time was sufficiently abundant that it's signature may now be found in rocks on the Martian surface. This is a non-falsifiable hypothesis in that while it may be proven by finding a single rock with evidence for life in it, it can only be disproved by examining every single rock on the Martian surface. What makes the problem even more serious is that unambiguous "biomarkers" have yet to be identified, while efforts to clearly prove or disprove purported evidence for life in one of the Martian rocks we already have in our laboratories has proven frustratingly unsuccessful and contentious. There is no *a priori* reason to expect greater clarity in returned samples: our knowledge of how to detect life within its broadest definition is still far from mature. We cannot predict how we will detect signs of life on Mars any better than we can predict if we will detect it.

Evolving Science Questions: Our picture of Mars continues to evolve as a consequence of the successes of the Mars Surveyor Program: New data returned by the Mars Global Surveyor (MGS) has not shown the carbonates or diverse minerals, or other evidence expected if there were an early, warm, wet climate. On the other hand, MGS data have uncovered new enigmas, such as the magnetic lineation of the southern highlands, which demand further investigation.

Exploration of a planet within a sustained and aggressive program is novel to NASA's robotic exploration endeavor. Typically, there has been substantial cycle time between missions to allow results to be digested and new directions discerned. The lack of cycle time within the Mars Surveyor Program undermines long-range planning which seeks to lay out detailed mission scenarios, especially if that program becomes overly focused on a single question. One of lessons of exploration is that our understanding of what is important will continue to evolve as we obtain more data and have additional time to analyze and model them. Neither the oxidizing soils nor the magnetic anomalies of Mars were predicted before the arrival of spacecraft and instruments to detect them. Both are important clues to Mars' past environment. Should the MSP as planned in late 1999, the return of a small amount of sample from the near surface at a restricted choice of landing sites will provide data for important questions about Mars. The existence of past or present life will probably not be among them - this makes use of sample return as a vehicle to search for life a high risk, long-odds endeavor. If sample return technologies are developed, a better posed and guaranteed scientific experiment would be to absolutely date the early geological provinces. In any case, evidence to date suggests that sample return simply cannot be undertaken within the bounds of the program without eliminating all other science. We seriously doubt whether this is scientifically warranted.

A Broad Scientific Agenda: The successes of the Mariner, Viking, and Mars Global Surveyor missions have revealed a complex and exciting world in our planetary neighbor. Many of the questions we have about Mars reflect concerns we have about our own world: How did the planet evolve and what determined the pathways? How does the climate system operate and what feedback systems operate to stabilize or destabilize the climate? How do geologic and tectonic processes operate and what determines their style, how does the planet interact with the solar wind and what does this imply for atmospheric evolution? What is the history of life and what determined this history?

The Mars Surveyor Program represents an open-ended commitment to explore our neighboring planet. This commitment results from the fascinating similarities of this world to our own, and the fact that if humans venture away from the Earth/Moon system, Mars will be the destination. In view of this commitment and the broad range of scientific questions, we see no valid reason to overstrain the program by rushing into sample return. As explorers we seek the thrill of taking each new step, not winning an Apollonian race. Mars is not going away: As long as the human species endures, it will continue to beckon new generations of explorers.

A TWO-STREAM MODEL FOR THE MARS EXPLORATION PROGRAM. M. I. Richardson[1], I. J. McEwan[2], and A. R. Vasavada [1]Division of Geological and Planetary Sciences, MC 150-21, Caltech, Pasadena, CA 91125 (mir@gps.caltech.edu), [2]Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095.

Introduction: The Mars Exploration Program represents an unprecedented opportunity to study and explore a planet and an environment beyond our own. While this opportunity represents the most important development in planetary exploration since the initial robotic survey of the solar system, it presents organizational and architectural challenges that have simply not been faced in the NASA robotic exploration endeavor to date. These challenges, of flying frequent, probably interrelated missions to Mars within a moderate, flat fiscal environment, were responded to in the late 1990's by the Mars Surveyor Program. The architecture that evolved within this program became singularly motivated by the search for life and singularly focused upon a sample return mission (to be executed over many opportunities.) The strategy behind this architecture sought to provide a clear rationale, develop common engineering systems, and centrally execute an ambitious technical program. We argue that the singular focus on the search for life and on the highly ambitious sample return strategy - while well motivated in terms of developing program coherence - forced the program into a non-optimal architecture and caused it to overreach its means. We will argue that the focused and centralized nature of the program seriously limited its ability to respond to failures or successes; overly strained the program by coupling broad constituencies with a highly ambitious technical approach, and ultimately stifled competition, creativity, and responsiveness as the Announcement of Opportunity (AO) system was abandoned in favor of facility development.

Proposal: In this abstract, we propose a new architecture for the program which will reinfuse community creativity while reducing programmatic risk resulting from individual mission failures. A major precept of this proposal is that the science goals of the program must return to those under which the Mars Surveyor Program was founded: a broad emphasis on planetary evolution, climate evolution and environment, preparatory science to support further exploration, each placed along side the search for life. Further, it must be realized that the while program is primarily justified as a scientific endeavor, it must also serve as its own technology and infrastructure development program. In order that the program doesn't become limited by inability to develop necessary technologies (by over-focusing on science) or worse, become fixed on developing technology alone (while neglecting science), appropriate balances need to be built into the program at an organizational level. Finally, the on-going nature of the program suggests that new discoveries and developments will occur during the course of the program, and that developing *a priori* a rigid sequence of missions may be the wrong way of thinking about program "architecture" entirely.

In view of these facts, we propose that the program be broken into two parallel "streams" or "branches". The first stream would be solely focused on the scientific exploration of Mars. This program would be organized in a similar manner to that of the Discovery program: integrated payload/spacecraft systems would be selected through an AO system, and would be led by a Project Manager / Principal Investigator team. The AO should be nearly the same for every opportunity: the proposal should be allowed to address any scientific issue (including those associated with human exploration) within the purview of the program, and the only constraints should be time and cost. The second stream would concentrate on the development and in-flight testing of technologies to be infused at a later date into the science stream. Particular missions flown in this stream would be selected by a mix of AO response and program commission. The direction of the technology stream should be determined by the perceived need for particular capabilities, as defined by the science and/or human exploration communities.

It is extremely important that large, distinct endeavors that do not fall within the scope, schedule, or cost constraints of either of these streams (such as Sample Return or a Mars orbital communications/navigations network) should not be "shoehorned" into them. Program stability dictates that the twin streams be considered the program core and that there funding be held fixed. Additional endeavors should be considered as separate line-items whose merit may be independently assessed.

The "Mars Discovery" Program: The relationship between science and technology within the late 1999's Mars Surveyor Program ultimately led to extremely disappointing results. The "science" pressure for sample return placed a highly challenging goal before the engineers, while the overreaching demands of developing the sample return technology eventually lead to an increasingly impoverished scientific program. The problems were exacerbated as scientists and engineers competed for the same pot of money. It was the implosion of the post-1998 program (sample return and its precursors), rather than the failures of the 1998 missions, which posed the greatest risk to the program as a whole.

Worthwhile scientific missions are carefully crafted scientific experiments: the gulf between doing the experiment right or simply doing something can be as yawning as the gulf between doing it right and not doing it at all. Compromise must be carefully weighed by the experimenter. For this reason, the PI-led integrated payload represents the pinnacle of scientific space exploration. But most importantly, it argues for separating concerns of technology development from scientific experiment. In the extreme case of the late 1990's Mars Surveyor Program, science was largely abandoned due to the imperative of developing the sample return technology. If the Mars Exploration Program is to be justified as an effort to explore and learn about Mars, there must be a continuing core element of the program that does that.

Given that we are interested in exploring Mars and that the program will continue to improve and shape our questions about the planet, an open and adaptable program is preferable. This suggests that a clear but broad statement of scientific goals should be established which will serve as the compass for the scientific program. Such goals can be based on COMPLEX/MEPAG reports, or on the results of a special program scientific panel (preferably an open one). In any case, we believe that the goals will ultimately be defined in terms of planetary evolution, climate evolution, environment, resources, and life. These program goals should be held as a constant target for the creativity of the scientific and engineering communities. As the ability to accomplish a scientific experiment is intimately related to the means by which the experiment is undertaken, we strongly suggest the Discovery mission approach of selecting an integrated mission model. Imposing spacecraft systems, or worse, setting up payload definition teams to define what goals can be addressed or even what instruments can be flown, greatly diminishes scientific freedom and hence stifles creativity within the program. Allowing a single, scientifically competent, AO-selected team to assess trades will guarantee the best science return and will eliminate the unnecessary interfaces that harmed the 1998 missions.

What is an "Architecture?" Central to the "Mars Discovery" vision for the science program is a necessary change in thinking about what an "architecture" is. This shift in thinking requires that we no longer attempt to plan out a defined sequence of missions into the foreseeable future (which is always shorter than we expect it is!), but develop those programmatic mechanisms which will allow the program to best adapt to the changing questions we have about Mars. Fostering opportunity for creativity within the program would further suggest this transition in thinking. Effort needs to be expended in designing mechanisms which allow numerous instrument concepts, spacecraft concepts, and mission concepts to be clarified that can openly compete for development funds and launch opportunities. Effort also needs to be expended on prudent designation of common elements, and the best way to make these elements available to the mission teams. In this sense, the program organization may become centered around two endeavors. The first would be providing a mission "incubator" environment, in which potential PI's or instrument/spacecraft engineers can easily find resources to better place them to compete for launch opportunities through the AO system - and better place NASA to launch the highest quality scientific missions. Such resources could include access to facilities such as mission planning tools and personnel, the provision of small "seed" grants for instrument or mission concepts, access to technical advise, and development of an instrument "registry" which might allow integrated payloads to be put together more readily and openly.

The second should be focused on how to develop the broad targets for the missions and emplacing mechanisms to determine which missions are selected for development and flight. We have already discussed goal definition. For selection, we advocate separate scientific and technical panels to assess the scientific value and technical feasibility of the missions. Final selection should be left to the program leadership, where scientific, technical, and political interests may be weighed.

Engineering Program: The engineering stream of the program would be implemented to eliminate "science pressure" from the task of developing important hardware. Such "science pressure" arguably harmed the development of long-range rovers and sample return technologies within the Mars Surveyor Program. The goals of the Engineering Program would be developed from perceived needs for exploration capabilities, such as robust landing systems, small network emplacement technology, balloon systems, *etc.* The Program could also test technologies and undertake some of the experiments necessary or likely useful for human exploration. These may include *in situ* resource processing, mechanical system suitability for prolonged exposure to the Mars environment, *etc*. The selection process could be facility driven, but we again recommend the advantages of the AO system.

Advantages of the Twin Stream Model: The twin stream model clearly separates the goals of technology development and scientific exploration in such a way that neither are neglected. Alternating launch opportunities within this structure increases program robustness, as common spacecraft system should not, in general, be scheduled for consecutive opportunities. It greatly increases the opportunity for scientific and technical progress by allowing the program to adapt to new information, and by reopening the realm of what is possible within the program. By allowing a variety of activities, it should provide an exciting era of vicarious exploration to engage the public well into the future.

The Athena Alpha Proton X-Ray Spectrometer (APXS). R. Rieder[1], J. Brückner[1], G. Klingelhöfer[2], R. Gellert[2], G. Dreibus[1], G. Lugmair[1], H. Wänke[1], and the Athena Science Team, [1]Max-Planck-Institut f. Chemie, Postfach 3060, D-55020 Mainz, Germany (rieder@mpch-mainz.mpg.de), [2]Institut f. Anorganische u. Analytische Chemie, Joh. Gutenberg-Universität, Staudinger Weg 9, D-55099 Mainz, Germany (klingel@mail.uni-mainz.de).

Introduction: During the Mars Pathfinder Mission in the summer of 1997, martian rocks were analyzed for the first time by a small instrument: the Alpha Proton X-Ray Spectrometer (APXS). This instrument was carried by the Sojourner rover to a number of soil and rock targets to obtain their elemental composition. The performance of the APXS permitted characterization of the landing site in an unprecedented way. New insights into soils and rocks on Mars were derived that could not have been obtained otherwise [1].

An advanced APXS instrument has been designed for the comet nucleus lander on the European Rosetta mission. The flight version is being completed presently, and a copy of this instrument will be used as part of the Athena rover payload for in-situ exploration of Mars.

Instrument Description: The new APXS is based on the successful APXS used for Pathfinder [2]. The new APXS sensor head has two modes to determine the elemental composition of a sample: Rutherford backscattering (alpha mode), and alpha and x-ray induced x-ray emission (x-ray mode). The surface of the sample is bombarded by 6-MeV alpha particles and x rays emitted by radioactive Curium-244 sources in the sensor head. The backscattered alpha particles are recorded by a thin alpha detector. The x rays are detected by a high-resolution silicon drift detector [3] that provides superior resolution (about 160 eV at 6.4 keV) compared to the Pathfinder APXS (260 eV). The x-ray mode is sensitive to major elements, such as Mg, Al, Si, K, Ca, and Fe, and to minor elements, including Na, P, S, Cl, Ti, Cr, and Mn. The alpha mode is very sensitive to C and O, and also to element groups of higher Z in vacuum. On the martian surface, there is an interference to C and O by the atmosphere which must be corrected for. The sampling depth is about 10 μm, with a detection limit of 0.5 to 1 weight percent depending on the element. The APXS is insensitive to small variations of the geometry of the sample surface because all major and minor elements are determined, and summed up to 100 weight percent.

Elemental Composition Determination: During the Pathfinder mission the rover approached many targets, including the rock "Barnacle Bill", which was the first martian rock ever analyzed. Many other soil and rock targets were visited during the rover mission (Fig. 1), which lasted significantly longer than expected. Depletion of the rover's primary batteries ultimately terminated APXS measurements, because the x-ray detector needed low temperatures (below -20 °C) during the night to operate satisfactorily.

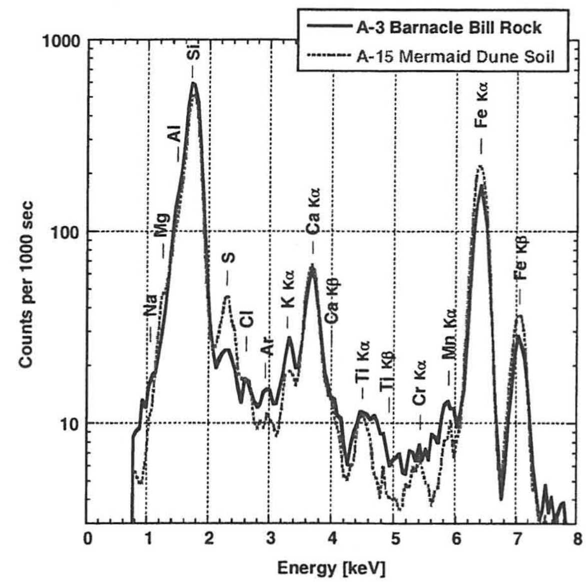


Figure 1 APXS x-ray spectra from Mars Pathfinder landing site: rock 'Barnacle Bill' and soil 'Mermaid Dune'.

Pathfinder APXS spectra were evaluated using several methods. In a first attempt, the peaks in the x-ray spectra were fitted using a Gaussian shape [1]. Later, their exact shape was derived, especially focusing on peculiarities of the detector response that resulted in spectral interferences produced by large peaks that lie close to weak peaks. This new method determined precisely the area of weak peaks in proximity to large ones. Similar improvements could be obtained for the spectral region in which the position of Mg, Al, Si, and P peaks are too close to be easily separated. The resolution of this region will be highly improved by the new detector and electronics in the Rosetta/Athena APXS.

Careful measurements were performed with an identical Pathfinder spare instrument under simulated martian atmospheric conditions. These measurements used certified geostandards and other validated materials, leading to improved re-calibration of the Pathfinder instrument. The quality of elemental composition of martian soils and rocks could be improved notably [4]. Also, the interference of the atmospheric component to the alpha spectra could be determined. Thus, the detection limit of carbon concentration (0.8 weight percent) was derived and, subsequently, no C could be detected in any of the martian samples.

Some Results from the Pathfinder Mission: Rocks at the Mars Pathfinder landing site are thought to have been deposited by catastrophic floods, originating in the ancient heavily cratered southern highlands. The APXS analyses of the rocks yielded unexpectedly high Si and K concentrations, pointing to a highly differentiated crustal material in this region of Mars, similar to what is found on Earth (some authors classified the Pathfinder rocks as andesites or islandites). These results are in contrast to the concept of a rather mafic martian surface that was inferred from Viking soil data and the composition of martian meteorites

The soils at the Pathfinder landing site have similar compositions to those measured at the Viking sites. This is interpreted as being due to eolian global dust distribution, at least at low to middle latitudes. The most plausible interpretation for the high concentrations of S and Cl in the martian soil is the formation of sulfates and chlorides by the interaction of volcanic gases with the surface material. In general, the Viking soils were interpreted as weathering products of a mafic crustal material. However, Pathfinder APXS data lead to the proposal that the surface material consists of both mafic and felsic components [5].

Assuming that the soil is a mixture of two components, it was shown that taking the Pathfinder rocks as the felsic end member, the mafic end member is adequately represented by the martian meteorites. It was further shown that the two end members cover large surface areas as large geologic units.

The recently obtained TES (Thermal Emission Spectrometer) data of the Mars Global Surveyor orbiter support the above-mentioned model. The TES team [6] has reported that Mars can be divided into basaltic units covering most of the southern highlands and andesitic units restricted mainly to the northern hemisphere.

The refined method of peak search in the APXS x-ray spectra permitted the determination of phosphorous in soils and rocks at the Pathfinder site [7]. Surprisingly, only small differences of the P concentration between soils and rocks were found. A mean P content of about 0.3 % was obtained. The soils at Viking and Pathfinder landing sites have high and very similar sulfur and chlorine concentrations when compared to the rocks analyzed with the APXS [1]. The observed good correlation of S versus Mg, Si, Cl, K, and Ti for the Pathfinder samples apparently reflects the fact that sulfur-poor rocks are partly covered with sulfur-rich soils. The absence of a correlation of P with sulfur in all Pathfinder samples indicates no enrichment of P in the rocks compared to soil as was found for the other analyzed incompatible element potassium. Commonly, during magmatic fractionation processes P behaves as an incompatible element like potassium and chlorine. A lack of a correlation of P and K in the Pathfinder rocks would be more in accordance with a sedimentary origin of these rocks rather than an igneous origin. Therefore, the term 'andesite' should be replaced by 'silica-rich', to avoid potential misconception from a strict classification.

Instrument Performance: The Athena flight APXS will be fully tested over the expected operational temperature range, and will be extensively calibrated under ambient martian conditions using "pure element" targets, certified geostandards, and validated meteorites and terrestrial rocks.

The sensor head contains radioactive alpha sources (~40 mCi = 1.5 GBq Cm-244), two detectors (for alpha particles and X rays) with appropriate collimators for the definition of the spectrometer's "field of view", and preamplifiers for the detector signals. The collimation and the use of coated sources (which slightly reduce alpha particle energy) work together to reduce significantly the atmospheric interference that was suffered on Pathfinder.

The nominal working distance between sensor and sample is 40 mm and is defined by a rectangular apron whose end is brought into direct physical contact with the sample. At contact, two doors that otherwise protect the detectors open. The inner surfaces of the doors also serve as calibration targets. The nominal diameter of the area viewed is about 40 mm.

Instrument mass is 640 g (including 10% margin). The instrument uses 1.5 W of power when operating, and the sensor head is 80 mm long and 52 mm in diameter.

The APXS will be mounted on an instrument arm along with the other Athena in-situ instruments. The instruments will be used together to thoroughly characterize the elemental composition, mineralogy, and texture of martian rocks and soils.

References: [1] Rieder R., et al. (1997) *Science, 278*, 1771-1774. [2] Rieder R., et al. (1997) *J. Geophys. Res., 102*, E2, 4027-4044. [3] Lechner P., et al. (1996) *Nucl. Instr. Meth. Phys. Res., A 377*, 346-351. [4] Brückner J., et al., to be published. [5] Brückner J. et al. (1999) *LPSC XXX*, Abstract #1250 (CD-ROM). [6] Bandfield J. L., et al. (1999) *AGU abstract*, P32A-03. [7] Dreibus G., et al. (2000) *LPSC XXXI*, Abstract #1127 (CD-ROM).

Safe Landings in Extreme Terrain

Tom Rivellini[1] , Gary Ortiz[2], Adam Steltzner[3] , [1]California Institute of Technology, Jet Propulsion Laboratory, MS 158-224, 4800 Oakgrove Drive, Pasadena, CA 91109, tpr@jpl.nasa.gov· [2]Jet Propulsion Laboratory, [3]Jet Propulsion Laboratory

Following the failure of the Mars Polar Lander and the re-evaluation of the Mars Sample Return mission status, a Safe Landing Tiger team was established on January 7, 2000. The charter of the team was to re-evaluate large scale (1000-2000 Kg) Mars lander designs with the principal objective being the assurance of safe landing in hazardous terrain. The tiger team developed a number of concepts, two of the most notable and promising concepts, are both based on a Mobile Lander paradigm. Unlike the Pathfinder and Surveyor class landers, this paradigm groups all of the landed equipment into one of two categories: EDL only equipment (ie not used after touchdown) and multi-use equipment, those used during and or after touchdown. The objective is to maximize the use of all equipment being brought to the surface by placing the bulk of the avionics and mechanical systems onto a much larger "rover" and leaving only the bare essentials on a "dead-on-arrival" landing system. All of the hardware that the surface roving mission needs is enlisted into performing the EDL tasks. Any EDL specific avionics not used after touchdown are placed on the landing system.

The first concept developed is called the pallet lander and is comprised of a low profile, large footprint mechanical framework which accommodates the descent propulsion system and a minimal set of avionics. The low profile of the pallet and the large scale of the Rover precludes the need ramps to allow rover egress. The basic principal of the pallet is that a lightweight semirigid central core takes the brunt of the primary impact, and in doing so is allowed to sustain irreversible but controlled damage. The rover is suspended above the core on 6 crushable shock struts. A reasonable analogy is that of a passenger car which sacrifices the vehicles integrity in order to protect the occupant (payload). As such, most of the pallet mechanical system is designed only to the levels required to ensure a safe stable landing even though large portions of the structure may be damaged during the landing. To prevent tipover, 6 outriggers are extended horizontally from the cetral core and are stabilized by tension only cables. This combination provides an extremely lightweight tension-compression outrigger system that is used for tipover stabilization but not primary touchdown impact mitigation.

The second concept developed by the tiger team is an airbag concept based on Mars Pathfinder heratige. In this concept an airbag system is wrapped directly around the large rover without the use of an exoskeletal frame such as the Pathfinder tetrahedron. Without the aid of this frame to self-right the rover after touchdown, a soft-goods concept was defined to ensure that the rover would be capable of self righting itself after a random touchdown and rollout. In order to maximize Pathfinder heratige, lobe diameter and inflation pressures were kept the same. The resuling airbag configuration coupled with a liquid propelled descent stage is capable of surviving landings on the required terrains .

The terrain requirements set forth for the tiger team were based on the work done in reference [1]. This study defined 3 representative terrains models described as lightly, moderately and heavily cratered terrains. The models generated combinations of slope, rock size and rock abundance. The program extrapolated from this study that lightly cratered terrains were the most viable landing sites for near term exploration. The touchdown requirement that stemmed from this report represented a 97% worst case. It was a continuum bounded by a 1 meter high rock (2 meter diameter half buried) on a zero degree slope, up to a .5 meter high rock on a 30 degree slope.

Using ADAMS dynamic simulation software, a high fidelity model of the pallet lander has been generated. The airbag system has also been modeled using a gas-bag simulation code developed for Pathfinder. Based on results from these both systems are capable of safe landings on a 30 degree slope with a 1 meter high rock (this excedes the requirement) and touchdown velocities with very large margins.

The team is currently designing a 3/8 test models of the pallet lander and airbag rollover system. The models will be used to validate the concepts to allow the team to make a quantified assesment of which concepet to carry forward into full scale development.

References:

[1] Doug Bernard and Matt Golombek, Preliminary Look at Hazard Models for Mars Landing, JPL IOM 3412-00-020, March 2, 2000.

This work was carried out at the Jet Propulsion Laboratory, Califonia Institute of Technology under a contract with the National Aeronautics and Space Administration.

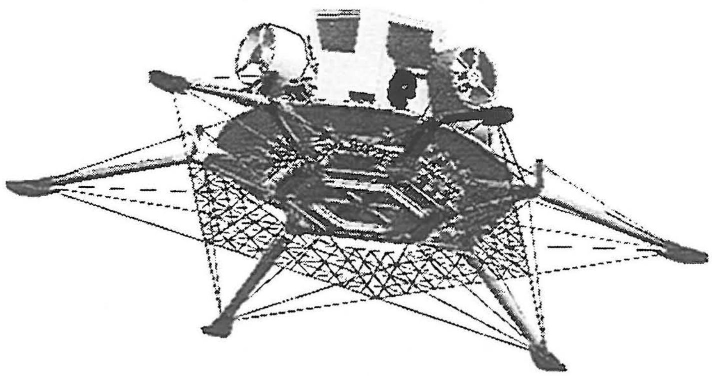


Figure 1: Bottom isometric view of pallet lander.

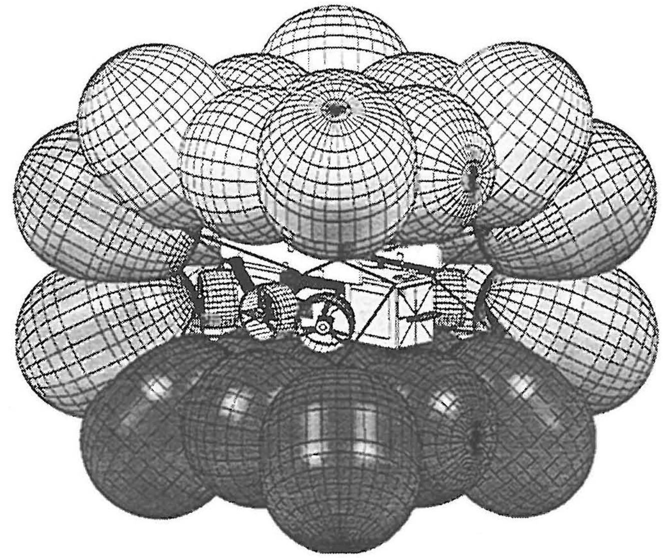


Figure 2: Isometric view of airbag landing system (2 bags removed for clarity).

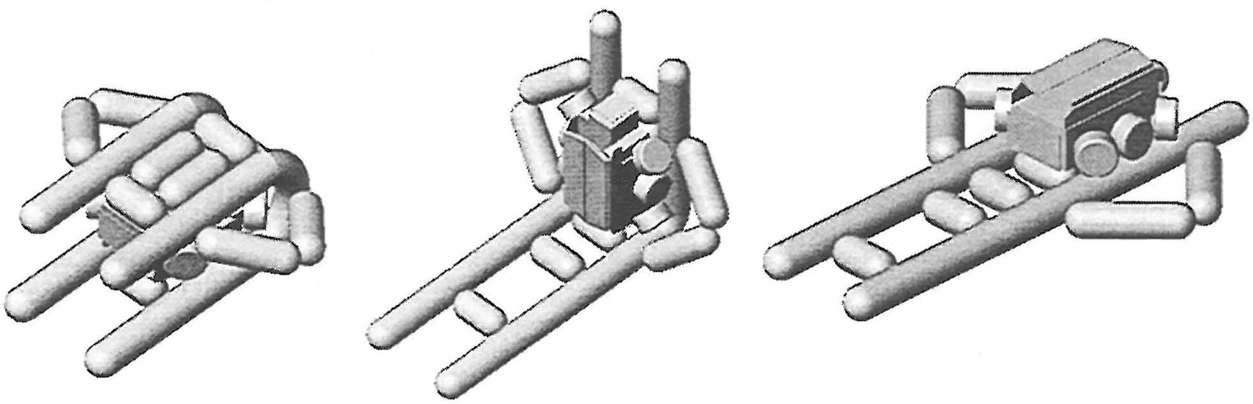


Figure 3: Inflatable self-righting system for the airbag lander (deflated impact bags not shown for clarity).

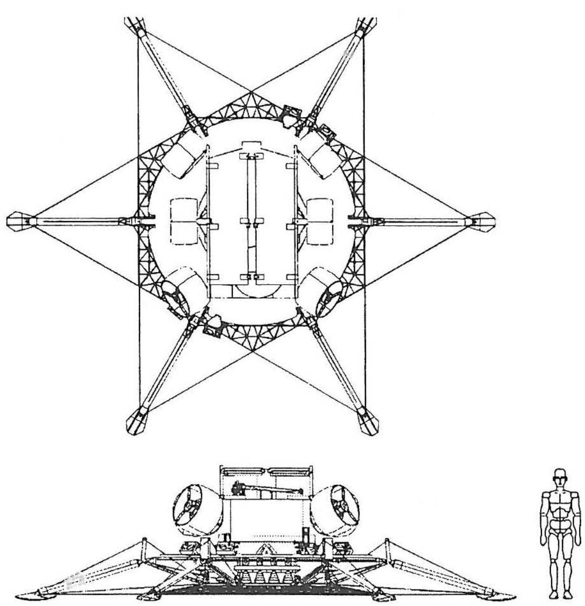


Figure 4: Top and front view of pallet lander.

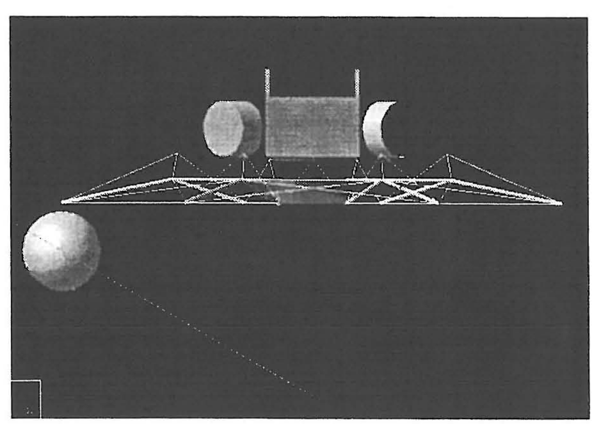


Figure 5: ADAMS simulation of pallet lander on a 30 degree slope with a 2 meter diameter rock half buried.

MARS MOBILE LANDER SYSTEMS FOR 2005 AND 2007 LAUNCH OPPORTUNITIES. D. Sabahi, J.E Graf, Jet Propulsion Laboratories, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, (e-mail:dara.sabahi@jpl.nasa.gov)

Introduction: A series of Mars missions are proposed for the August, 2005 launch opportunity on a medium class EELV with a injected mass capability of 2600 to 2750 kg. Known as the Ranger class, the primary objective of these Mars mission concepts are:

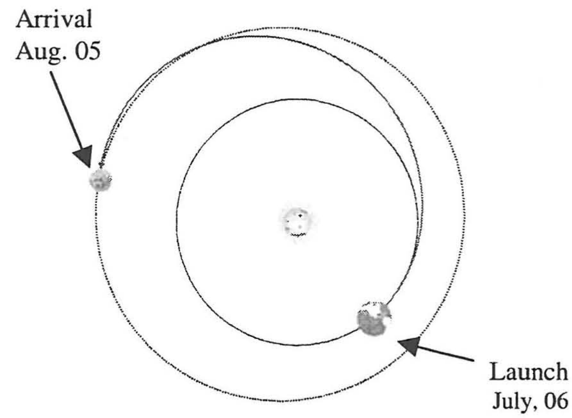
- Deliver a mobile platform to Mars surface with large payload capability of 150 to 450 kg (depending on launch opportunity of ' 05 or '07).
- Develop a robust, safe and reliable workhorse entry, descent & and landing (EDL) capability for landed mass exceeding 750 kg.
- Provide feed forward capability for the '07 opportunity and beyond.
- Provide an option for a long life telecom relay orbiter.

A number of future Mars mission concepts desire landers with large payload capability. Among these concepts are Mars sample return (MSR) which requires 300 to 450 kg landed payload capability to accommodate sampling, sample transfer equipment and a Mars ascent vehicle (MAV). In addition to MSR, large in-situ payloads of 150 kg provide a significant step up from the Mars Pathfinder (MPF) and Mars Polar Lander (MPL) class payloads of 20 to 30 kg. This capability enables numerous and physically large science instruments as well as human exploration development payloads. The payload may consist of drills, scoops, rock corers, Imagers, spectrometers, in-situ propellant production experiment, and dust and environmental monitoring.

Mission Description: Mars ranger class landers (MRL) are high performance landers with long range roving capability, "dead on arrival" (DOA) landing gear with a mobile platform that can support a robust payload complement. Mars Rangers include a robust highly reliable entry, descent and landing (EDL) system with a large, multi-kilometer range mobile platform. Another option includes a cruise stage or a long life telecom orbiter accompanying the interplanetary phase of the mission.

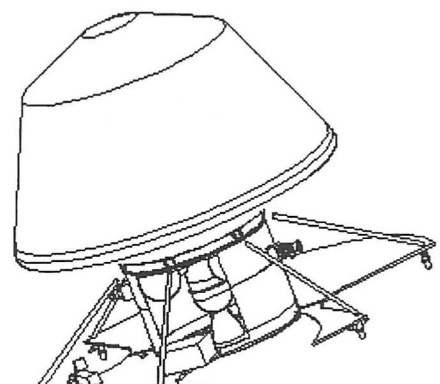
The Mars Ranger family of options have 3 key mission phases: cruise, EDL, and surface.

Cruise Phase : For the '05 opportunity, all missions use a type-II transfer trajectory. Launch is in August of 05 with a three week launch window (with a C3 of 18 km^2/s). Arrival is in July of '06 at 1:00 PM local solar time, in late spring in the Northern Hemisphere. The cruise duration is 11 to 12 months.



Transfer Trajectory

The cruise phase utilizes a cruise stage with independent monoprop propulsion and optical navigation capability. The cruise phase delivers the entry vehicle containing the lander on a precision direct entry trajectory. For one option a relay orbiter replaces the cruise stage. The orbiter will perform orbit insertion maneuvers after lander separation. The primary objective of the orbiter is to provide telecom relay capability for the 2005 and future landed missions. The orbiter will also have an imaging capability utilizing the optical navigation camera.



Mars Range Network Cruise Configuration with Relay Orbiter

MARS MOBILE LANDER SYSTEMS: D. Sabahi and J.E Graf

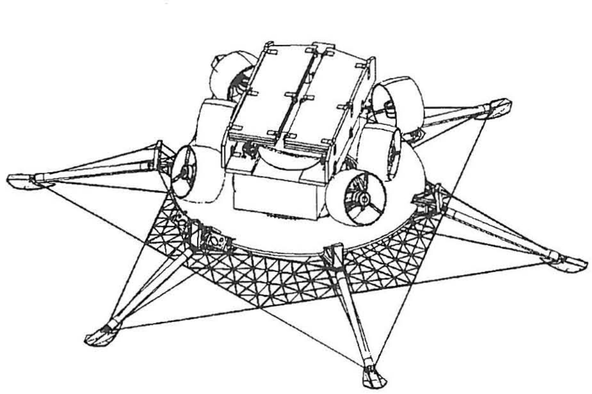
EDL Phase[1]: This is the most critical phase of the mission and requires significant technology development in order to meet reliable landing requirements.

The key EDL requirements are:

- 5.0-km landing radius
- 1.0-meter rock tolerance
- 30-deg slope tolerance
- < 2100 kg entry mass
- < 1500 kg landed mass

The EDL system meets and exceeds the above requirements by utilizing robust entry, descent and landing subsystems. The EDL system utilizes the following key subsystems:

- Entry vehicle with aeromanuver capability for enhanced performance.
- Subsonic parachute in addition to supersonic parachute for enhanced performance.
- Hazard avoidance capability for increased reliability.
- Throttled powered descent engines to increase reliability.
- A pallet or airbag with self-righting landing system for increased reliability[2].
- Avionics redundancy, selective cross-strapping and hot backup for increased reliability.
- X-band direct-to-Earth semaphores and UHF real time telemetry relay to an orbiting asset.



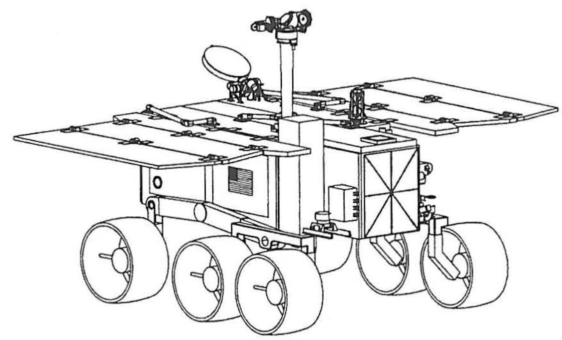
Lander/Rover Concept on Pallet Landed Configuration

Surface Phase[3]: The surface mission is a 90-sol mission with 90-sol extended mission goal. The surface mission will be in a latitude band of 5^{O} to 25^{O} North. A solar conjunction will occur 60-sols into the landed mission from October 13 to November 2.

The MRL concepts are known in the Summary matrix. One, called the Range Rover, employs a cruise stage that is discarded after separation. The lander supports up to seven instruments and has the volume and interfaces required for a MAV. Another, called the seeker is similar to the Range Rover, except it is smaller in size and cannot accommodate a MAV. The third, called Tracker has a relay orbiter instead of a cruise stage and can support up to seven instruments but no MAV. ity.

In all options the rover utilizes X-band direct to Earth telecom link and UHF relay link to an orbiting asset.

Additional options for the surface phase are under study. These options include stationary lander or multiple Rover configurations.



Mobile Large Rover with MAV Capability

Preliminary Mission Name	Mobile Lander	Cruise Stage	Orbiter	Instruments	MAV	Launch Vehicle
Range Rover	yes	yes	no	up to 7	capability only	Delta-4+ (5,4)
Seeker	yes	yes	no	up to 7	no	Delta-4+ (5,4)
Tracker	yes	no	yes	up to 7	no	Atlas-V 521

Mission Options Summary Matrix

Based on preliminary studies, all the options have generous resource margins as shown in the margin table below:

- Mass Margin 30% to 37%
- Power Margins > 45 %
- Battery SOC > 35 %
- Data Margin – X-Band 25%
- Data Margin X-band+UHF >200%
- Landing Velocity Margin 4 times
- Propellant Margin 30%
- Surface Life Margin 100%

References: [1] Thurman, S. W., (2000) LPI Workshop, Houston, TX. [2] Rivellini, T. P., Ortiz, G. M. and Steltzner, A. D. (2000) LPI Workshop, Houston, TX. [3] Eisen, H. J., (2000) LPI Workshop, Houston, TX.

COMMON IN-SITU CONSUMABLE PRODUCTION PLANT FOR ROBOTIC MARS EXPLORATION.

G. B. Sanders, J. R. Trevathan, T. A. Peters, and R. S. Baird. NASA/Johnson Space Center

Introduction: Utilization of extraterrestrial resources, or In-Situ Resource Utilization (ISRU), is viewed by the Human Exploration and Development of Space (HEDS) Enterprise as an enabling technology for the exploration and commercial development of space[1]. A key subset of ISRU which has significant cost, mass, and risk reduction benefits for robotic and human exploration, and which requires a minimum of infrastructure, is In-Situ Consumable Production (ISCP). ISCP involves acquiring, manufacturing, and storing mission consumables from in-situ resources, such as propellants, fuel cell reagents, and gases for crew and life support, inflation, science and pneumatic equipment.

One of the four long-term goals for the Space Science Enterprise (SSE) is to "pursue space science programs that enable and are enabled by future human exploration beyond low-Earth orbit – a goal exploiting the synergy with the human exploration of space"[1]. Adequate power and propulsion capabilities are critical for both robotic and human exploration missions. Minimizing the mass and volume of these systems can reduce mission cost or enhance the mission by enabling the incorporation of new science or mission-relevant equipment. Studies have shown that in-situ production of oxygen and methane propellants can enhance sample return missions by enabling larger samples to be returned to Earth or by performing Direct Earth Return (DER) sample return missions instead of requiring a Mars Orbit Rendezvous (MOR). Recent NASA and Department of Energy (DOE) work on oxygen and hydrocarbon-based fuel cell power systems shows the potential of using fuel cell power systems instead of solar arrays and batteries for future rovers and science equipment. The development and use of a common oxygen/methane ISCP plant for propulsion and power generation can extend and enhance the scientific exploration of Mars while supporting the development and demonstration of critical technologies and systems for the human exploration of Mars.

In-Situ Propellant Production Sample Return Mission: Numerous studies have shown that the benefit of making propellants on Mars versus bringing them from Earth increases with corresponding increases in desired sample size or mission delta-V requirements. Since propellant mass typically makes up 60 to 80% of the ascent or Earth return vehicle mass, ISPP on the Mars surface can reduce the initial mission mass required in low Earth orbit by approximately 20% to 30% as compared to carrying all required propellant to the Mars surface from Earth. An even greater leverage can occur for Mars missions when in-situ water can be processed.

Over the last several years, the Johnson Space Center (JSC) has performed joint and independent mission and process trade studies for robotic ISPP sample return and human Mars missions, examining both propulsion and propellant production options. Even though there are numerous processes to convert Mars atmospheric carbon dioxide (CO_2) into oxygen (O_2) and other useful products, trade studies based on complexity, performance, and technology readiness currently show that the Sabatier/Water Electrolysis (SWE) process combined with the Zirconia CO_2 Electrolysis (ZCE) process to make O_2 and methane (CH_4) is the preferred propellant production option if Earth supplied hydrogen (H_2) is used. The SWE is a two-step process. First H_2 and CO_2 are fed into the Sabatier reactor at 250 C to produce CH_4 and water (H_2O). Then the H_2O is electrolyzed into O_2 and H_2, and the H_2 is recycled and combined with Earth or Mars supplied hydrogen to make more CH_4. Since the SWE process produces O_2 and CH_4 at a 2:1 mass ratio with Earth supplied H_2, and propulsion systems require a >3:1 mass ratio, an extra oxygen generation step (such as the ZCE) is required. The ZCE is a solid state ceramic device that combines the effects of high temperature (>800 C) and the presence of a catalyst to dissociate CO_2 into oxygen ions and carbon monoxide. The oxygen ions produced are conducted through the porous zirconia membrane with a voltage potential and combined into oxygen molecules on the opposite side of the membrane. Depending on sample size and ascent vehicle Delta-V requirements (MOR vs DER), a production rate of approximately 0.5 to 4 kg of propellant per sol for 300 to 500 days is required.

An area of chemical processing technology currently under development that can significantly reduce the mass, volume, and power of ISCP and fuel cell reagent processing systems, and thereby further reduce the mass and volume associated with ISCP-based robotic missions, is microchannel chemical/thermal system (MCTS) technology[2]. The use of microchannel and etched-plate fabricated reactors, heat exchangers, mixers, and separators allows for rapid heat and mass transport, improved temperature and reaction kinetic control to produce non-equilibrium chemical products, reduced gravity environment effects (since surface forces dominate over gravity forces), high productivity per unit volume, and enhanced thermal integration for energy efficiency without a reduction in throughput compared to conventional chemical processing systems. Preliminary system analyses by JSC and

DOE/Pacific Northwest National Laboratory (PNNL) show a factor of four reduction in mass and an order of magnitude reduction in volume compared to the baseline SWE and ZCE system.

Fuel Cell Powered Rovers & Science Equipment With In-Situ Produced Reagents: The SSE Mars Surveyor Program currently utilizes solar arrays and batteries to power landers and rovers. While relatively simple and successful, solar array/batteries do have some disadvantages, such as low energy capabilities, limited rover size, and daylight only (6 to 8 hours) operations. The current reference mission for human exploration of Mars assumes the use of a nuclear reactor to supply power to the ISCP plant and human habitat, and a Radioisotope Thermoelectric Generator (RTG) to power rovers for surface exploration. In an effort to investigate non-nuclear power options for human exploration, and to extend robotic surface operations, the use of fuel cells instead of solar arrays/batteries for robotic outpost rovers and science equipment is currently under investigation. JPL Team X and JSC completed a top-level trade study (Nov. 1999) comparing the capabilities of a solar array/battery powered rover against a high-pressure H_2/O_2 fuel cell powered rover. The fuel cell rover consisted of a rover vehicle with a Proton Exchange Membrane fuel cell (100 W to 200 W), and O_2, H_2, and H_2O tanks, and the lander included similar storage tanks and an electrolysis unit to convert H_2O into high-pressure O_2 and H_2. For the fuel cell rover to recharge, it has to return to the lander, and exchange water produced during electrical generation with new fuel cell reagents. The fuel cell enabled continuous roving operations, lights for nighttime operation, and use of power intensive science instruments. The study showed that selection of solar arrays/batteries versus fuel cells is based primarily on mission requirements, such as allowable rover size, desired mission operations (short vs long surface stays and daylight vs continuous operations), and science instrument power requirements. Solar array/battery power generation best supports size constrained rover missions with long duration surface stay times to compensate for lower science instrument power and daytime only operations.

Based on MCTS fuel processing and man-portable power generation development activities at PNNL and in-situ production of oxygen and methane development within NASA, JSC is currently examining a fuel cell powered robotic rover mission based on technology and systems under development for a Mars sample return mission utilizing ISPP. Initial calculations show that little modification to the sample return propellant production, liquefaction, and storage hardware and production rate would be required to support a fuel cell powered rover for a robotic outpost mission.

Current ISCP Development Activities: JSC is currently coordinating and focusing the Agency's development of ISCP technologies and systems for robotic and human exploration[3]. The goal of this program is to develop and validate ISPP technologies and systems to support a Mars ISPP sample return mission in 2007.

The SWE process for ISPP has primarily been developed by Lockheed Martin Astronautics with support from Hamilton Sundstrand. This chemical processing system was originally built and tested for NASA from 1994 to 1996, and has since been modified and upgraded by both LMA and JSC to operate under simulated Mars surface conditions. JSC is currently testing this unit, and is working on designing a second generation SWE system based on enhanced technologies and lessons learned. For the ZCE, both the University of Arizona (UofA) and Allied Signal have developed and tested the most advanced ZCE technology to date. The Oxygen Generator Subsystem on the Mars ISPP Precursor (MIP) flight experiment (originally manifested on the 2001 Mars Surveyor Lander) incorporates a single UofA (1" dia.) ZCE cell, and the recently selected PROMISE flight experiment will incorporate two 3-cell (2" dia.) stacks based on the MIP design. Allied Signal has built and tested the only multicell ZCE stack to date. MCTS technology has been under development at PNNL for several years for automotive fuel cell processors and man-portable power generation and thermal control units under DOE and Department of Defense (DOD) funding. Researchers at PNNL and JSC, under a currently funded 3 year effort, are collaboratively developing MCTS technology for Mars ISPP applications.

Conclusion: A common ISCP plant to produce oxygen and methane can enhance both Mars sample return and rover science missions while supporting the development and demonstration of critical technologies for the human exploration of Mars. Based on continuing development of the technologies and processes identified, science missions as early as 2007 can be supported with minimal program and mission risk.

[1] NASA Strategic Plan, 1998, NASA Policy Directive-1000.1.

[2] Wegeng, R., Sanders, G., "Microchemical and Thermal Systems for In Situ Resource Utilization", LPI No. 963, Feb., 1999

[3] Sanders, G. B., "ISRU: An Overview of NASA's Current Development Activities and Long-Term Goals", AIAA 2000-1062, 38th Aerospace Sciences Meeting, Reno, NV., Jan. 2000

TOOLS FOR ROBOTIC IN SITU OPTICAL MICROSCOPY AND RAMAN SPECTROSCOPY ON MARS. C. H. Schoen[1] and D.L. Dickensheets[2], [1]Detection Limit, Inc. (555 General Brees Rd. Laramie, WY 82070), [2]Montana State University (610 Cobleigh Hall, Bozeman, MT 59717).

Robotic missions to Mars require remote diagnostic tools for detecting evidence of former life. Laser Raman spectroscopy is eminently suitable for this quest as its light-scattering principle permits non-intrusive analysis. Integration of Raman spectroscopy with optical microscopy correlates biochemical and morphological data. Vibrational Raman spectra identify component moieties of unknown target biomolecules such as pigments involved in photosynthesis and UV-protection. Antarctic desert analogues of potential early Mars habitats support localized anaerobic photosynthetic bacteria and widespread cyanobacteria containing chlorophyll as a primary pigment. Chlorophyll and accessory pigments (e.g. phycocyanin) autofluoresce at visible wavelengths (e.g. 530 nm). Although valuable for epifluorescence microscopy, this interferes with Raman spectra by producing curved baselines and instrument saturation. Fourier Transform Raman spectroscopy (FTRS) with near-IR excitation avoids most fluorescence while producing distinct and unique spectra for a wide range of wavenumbers. These spectra identify key moieties, such as the porphyrin nucleus of chlorophyll, which can be detected in whole communities from deserts with features common to potential habitats of early Mars.

FTRS requires a heavy interferometer-based detector. Dispersive Silicon CCD detectors are much smaller but not sensitive at 1064 nm. Excitation at 852 nm is a CCD-compatible compromise. Although currently lacking the clarity of 1064 nm spectra, it avoids the substantial fluorescence induced by lasers at shorter wavelengths (e.g. 633 nm).

Figure 1 illustrates Raman spectra of *Acarospora chlorophana*, a yellow-pigmented epilithic desert lichen from Victoria Land, Antarctica. Spectra from the same specimen were compared with a bench-top 1064 nm FTRS instrument and a miniature 852 nm confocal microscope/Raman spectrometer system (mass <1 kg), under development with NASA funding for potential Mars landers and shown in Figure 2. Its small probe head (< 100 cm^3) contains the confocal microscope and Raman filters, fiber-coupled to the laser light source and spectrometer housed in an electronics bay. The confocal microscope (imaging at video rates of 30 frames per second) comprises a Silicon microelectromechanical (MEMS) bi-axial scanning mirror, precision molded aspheric lenses and piezoelectric focus control. The light source for both components is an 852 nm distributed Bragg reflector diode laser. Rayleigh scattered light is detected to form the confocal image, while Raman shifted light is separated by a Raman filter set and detected with a dispersive CCD-based compact spectrometer. Spectral resolution is 8 cm^{-1} over a range from 400 cm^{-1} to 1800 cm^{-1}. Raman spectra may be obtained over a variable field-of-view by controlling scanning in the microscope, from a minimum spot size of 1 μm to full field of 250 μm ×

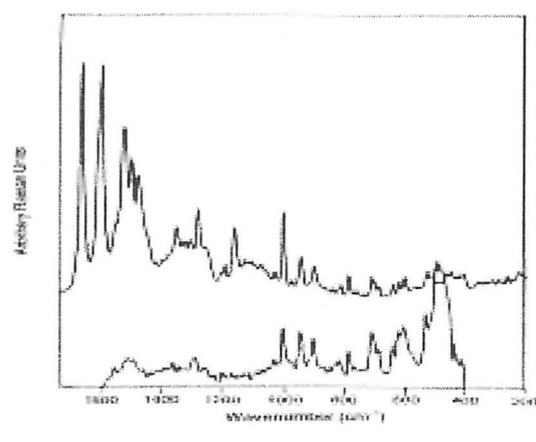


Figure 1 Raman spectra of *Acarospora chlorophana*. Top trace from 1064 nm FT-IR spectrometer (Bruker IFS66). Bottom trace from 852 nm dispersive CCD spectrometer.

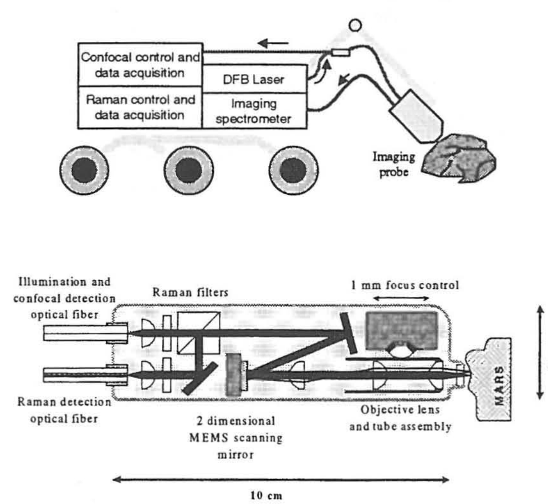


Figure 2. Miniature Confocal Microscope and Raman Spectrometer

250 μm. . The 852 nm spectrum here was obtained while scanning a field measuring 60 μm × 100 μm with incident power of 20 mW for a duration of 300 seconds and a total energy dose of 6 Joules. Figure 3 shows a confocal microscope image with accompanying spectra for a Calcite sample.

Of particular interest is a newly developed and patented dispersive 1064 Raman system utilizing volume holographic gratings and InGaAs arrays (Figure 4). Initial results show that the S/N is equivalent to that of the 852 nm system that uses a silicon based CCD array. In addition, the fluorescence problems that plague Raman systems using shorter wavelengths (including 852 nm) when analyzing many biomolecules are avoided with a system operating at 1064 nm. These systems are being developed through Micron Optical Systems, Inc. in Norfolk VA, and promise the first 1064 nm system that will satisfy space size, weight and performance requirements.

We believe that future development efforts to realize in situ Raman spectroscopy coupled to optical microscopy will benefit from these recent advances to produce compact instruments for near IR spectroscopy and couple them to miniaturized optical microscopes.

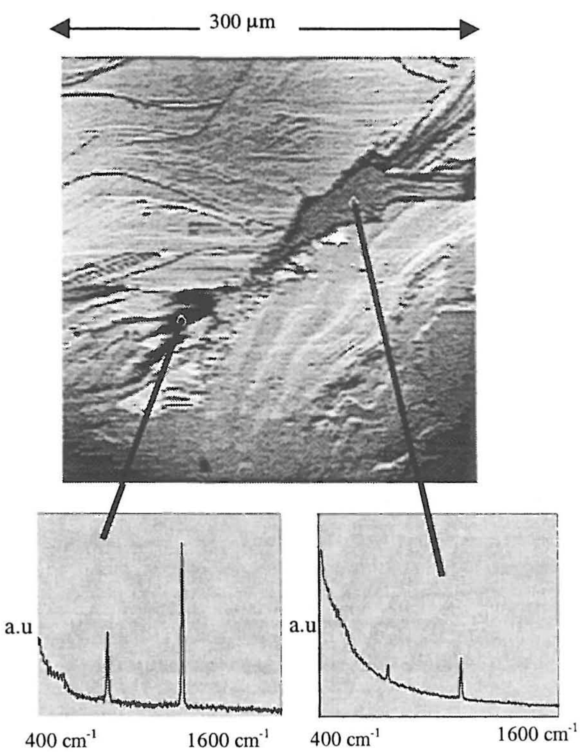


Figure 3. Confocal image of Calcite sample with point-specific Raman spectra, obtained with miniature 852 instrument.

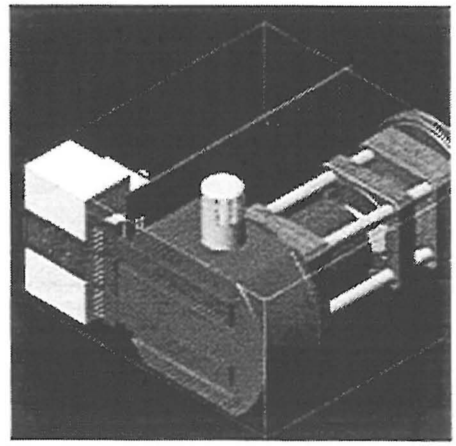


Figure 4 Combined 1064 laser/dispersive spectrometer assy < 1000 cm3.

OPTICAL DATING OF MARTIAN EOLIAN SEDIMENTS BY ROBOTIC SPACECRAFT. Derek W. G. Sears[1], Kenneth Lepper[2], and Stephen W. S. McKeever[3]. Arkansas-Oklahoma Center for Space and Planetary Science, [1]Cosmochemistry Group, Dept. of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701. Dsears@comp.uark.edu. [2]Environmental Science Program / Dept. of Physics, 145 Physical Sciences Bldg., Oklahoma State University, Stillwater, OK 74078. Lepper@okstate.edu [3]Dept. of Physics, 145 Physical Sciences Bldg., Oklahoma State University, Stillwater, OK 74078. u1759aa@okstate.edu.

Introduction: The Martian polar ice caps record a wealth of information about the past history and climate of Mars, but as pointed out by Clifford *et al.* in the summary of the *First International Conference on Mars Polar Science and Exploration* [1], "The single greatest obstacle to unlocking and interpreting the geologic and climatic record preserved at the [martian] poles is the need for absolute dating." Stratification in the polar caps arises, at least in part, from the incorporation of eolian material into the ice [2], and dune fields near the poles indicate eolian transport is an important surfical process in this region of Mars [3]. Eolian materials are ideally suited for sediment dating using luminescence methods. Luminescence dating techniques have been used successfully to make absolute age determinations for numerous terrestrial Quaternary eolian deposits. Clifford *et al.* [1] also concluded that cost, simplicity and potential for miniaturization make luminescence dating more feasible than isotopic methods for *in situ* dating by robotic landers. In fact, the water detection equipment of the Deep Space 2 microprobes and the MECA on the Mars Polar Lander contain components similar to those required for luminescence dating.

Theoretical Considerations. Over geologic time, ionizing radiation from the decay of naturally occurring radioisotopes and from cosmic rays liberates charge carriers (electrons and holes) within silicate mineral grains. The charge carriers can subsequently become localized at crystal defects and are thus accumulated at these "electron traps". Recombination of the charge carriers results in photon emission, *i.e.* luminescence. The intensity of luminescence produced is proportional to the number of trapped charges, and thereby the time elapsed since trapping began. Experimentally, thermal or optical stimulation can be employed to liberate trapped charge producing thermoluminescence (TL) or optically stimulated luminescence (OSL), respectively. The response of the luminescence signal to ionizing radiation and the local ionizing radiation dose rate of the deposit must also be determined.

For successful application to dating, (i) the luminescence signal should increase monotonically with absorbed radiation dose, (ii) once promoted to traps, the electrons should remain trapped and not find ways of returning to the ground state, in other words the signal should be stable, and (iii) the signal should be essentially zero when the sediments are deposited so that the method actually determines the time interval since a physically significant event occured, namely the deposition of the grains.

The range of the method depends on mineralogy and local dose rates, but is typically ~1ka BP to ~150ka BP. Pore water in terrestrial sediments attenuates the external radiation dose which has the effect of extending the this accessible age range. The attenuation effect of the water ice and carbon dioxide ice of the Martian ice caps and the local ionizing radiation dose rates are unknown but amenable to laboratory experiments.

Reviews of the development of luminescence dating, and detailed discussions of procedures and limitations can be found in the references [4,5]. We have been exploring these questions and investigating the potential of luminescence dating for use on robotic Mars landers. Here we describe some of our results.

Characteristics of Martian Eolian Sediments. Data from the Pathfinder mission indicates that surface materials on Mars are similar to terrestrial basalts and andesites [6]. The primary components of such rocks are pyroxene, calcic plagioclase, and biotite, but spectroscopy of the martian surface suggests the presence of significant amounts of poorly crystalline iron-oxides and clay minerals, reflecting the importance of chemical weathering of surface deposits [7]. In this case, secondary quartz would also be expected in the suface sediments [8]. The morphological similarity between terrestrial and Martian dunes suggests that martian dunes are composed of sand-sized grains [2]. Eolian material incorporated in the polar ice caps is poorly determined at present, but is believed to be sand and smaller particles [3].

Preliminary investigations of the Luminescence Properties of the Mars Soil Simulant JSC Mars-1. We have conducted a preliminary characterization of the fundamental luminescence properties of the JSC Mars-1 soil simulant. The results indicate that the bulk sample has a wide dynamic radiation dose response range (Fig. 1), with no unusual or prohibitive signal instabilities, and is susceptible to solar resetting (Fig. 2) [9]. These three properties form a stable base for future investigation of the material's utility for luminescence dating. Further research on JSC Mars-1, other terrestrial analogs and, perhaps, Martian materials is needed to develop luminescence dating procedures and protocols for remote application to Martian samples.

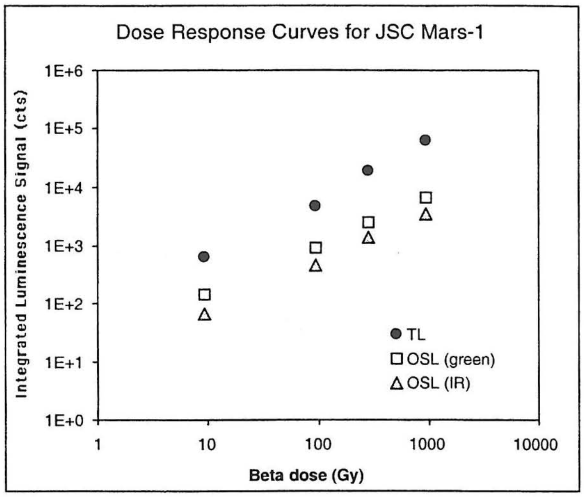


Fig. 1. Luminescence response to radiation dose for JSC Mars-1 soil simulant. Measurable dose response range exceeds that of terrestrial materials commonly used for luminescence dating.

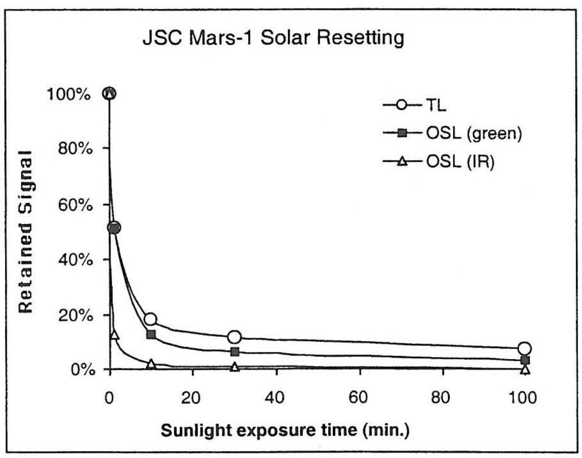


Fig. 2. Solar resetting curves for JSC Mars-1, shown as the percentage of luminescence signal retained after timed exposures to sunlight, exhibit responses typical of terrestrial materials commonly used for luminescence dating.

An *in situ* OSL dating experiment. We envision the development of DS2-like "dating-probes" or a deck-mounted luminescence dating module suitable for deployment by lander or rover on the surface of Mars. The essential elements of this system would include a sample collection device (similar to the soil auger aboard DS2), a sample chamber, an optical stimulation source (IR laser with filters and lenses), a light sensor (photodiode) and an irradiation source (*e.g.* a low level

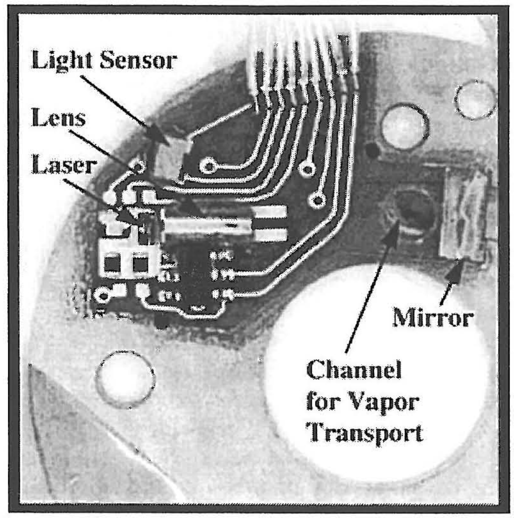


Fig. 3. Water determination apparatus on the DS-2 is very similar to that required for optical dating.

^{90}Sr β source). Many of these components already exist in the soil water detection experiment currently aboard the DS2 Mars microprobes (Fig. 3) and the MECA microscopy station on the Mars Polar Lander.

Also needed is a mechanism for determining the background radiation dose rate in the sample location. To do this we propose use of an OSL dosimeter probe consisting of, for example, carbon-doped sapphire [10] or silica glass doped with rare earth elements [11]. After exposure of the OSL dosimeter in the martian soil for a suitable period, the OSL signal can be read via stimulation with the IR laser.

With the components of such a system in place on a suitable platform (*i.e.* microprobe, lander, rover), a full OSL dating protocol could be carried out using procedures predetermined from laboratory experiments here on Earth. Data from the experiment would be transmitted to Earth where the age calculations would be performed. As an added bonus of this system, the OSL dosimeter will record the low-LET (<15keV μm^{-1}) dose absorbed during transit from Earth to Mars. Reading the OSL dosimeter upon arrival at Mars will reset the signal for *in situ* dosimetry and, at the same time, yield the Earth-Mars low-LET transit dose.

References: [1] Clifford S.M. et al. (2000) *Icarus* **144:** 210-242 [2] Greeley R. *et al.* (1992) *in* Mars *ed. Kiefer H. H. et al.* [3] Thomas P. et al. (1992) *in* Mars *ed. Kiefer H. H. et al.* [4] Aitken M. J. (1985) Thermoluminescence Dating. [5] Wintle A. G. (1997) *Radiation Measurements* **27:**769-817. [6] Rieder R. *et al.* (1997) *Science* **278:**1771-1774. [7] Soderbolm L. A. (1992) *in* Mars *ed. Kiefer H. H. et al.* [8] Gooding J. L. *et al.* (1992) *in* Mars *ed. Kiefer H. H. et al.* [9] Lepper, K. and McKeever, S.W.S. (2000) *Icarus* **144:**295-301. [10] Bøtter-Jensen L. and McKeever S.W.S. (1996) *Radiation Protection Dosimetry*, 65, 273-280. [11] Justus, B. *et al.* (1997) *Radiation Protection Dosimentry* **74:**151-154.

Combined Remote Mineralogical and Elemental Measurements From Rovers. F. P. Seelos[1], R. C. Wiens[2], D. A. Cremers[2], M. Ferris[2], J. D. Blacic[2], and R. E. Arvidson[1], [1]Department of Earth and Planetary Sciences, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, seelos@wunder.wustl.edu, Tel: 314 935 4888, Fax: 314 935 4998, [2]Los Alamos National Laboratory, Los Alamos, NM 87545.

The FIDO/K9 Year 2000 Mars Prototype Rover field trials at the Lunar Crater Volcanic Field, Blackrock Summit, NV provided the opportunity for the tandem acquisition of Laser Induced Breakdown Spectroscopy (LIBS) data and VISIR reflectance data from select geologic targets in a non-laboratory environment [1]. The LIBS data were acquired by the LANL LIBS instrument mounted on the Ames Research Center K9 rover [2], and the VISIR reflectance data were acquired with an ASD Full Range portable spectrometer. The ASD instrument has a wavelength range of 350 to 2500 nm and a spectral resolution of 3 to 10 nm.

LIBS is focused on the determination of the elemental composition of a target, whereas VISIR reflection spectroscopy is more useful in inferring the mineralogy. By acquiring both types of data in tandem from rovers, a more complete characterization of the target can be obtained.

The samples that were measured in the field are pictured in Figure 1. It should be noted that sample A11/A14 is a single target separated into two pieces. In addition, the reflectance data for sample A04 proved to be unreliable so analyses are not included in this report. These considerations reduce the number of samples in the analysis to ten.

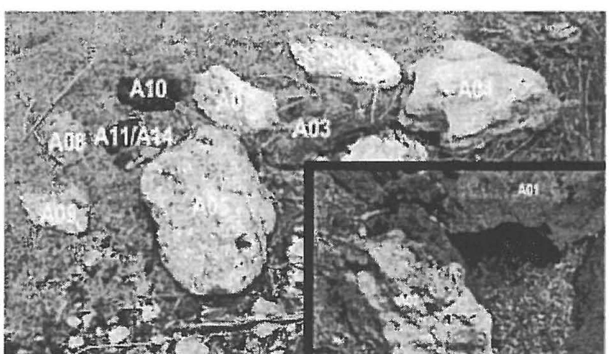


Figure 1 - Samples measured in the field with both the LIBS and reflectance instruments. Sample A05 is approximately eight inches long.

Analyses of the reflectance spectra led to the separation of the samples into four distinct groups. These groups are defined as follows: Group 1, Basalt endmember; low and generally featureless reflectance spectra. Group 2, Goethite endmember; characteristic goethite Fe^{3+} spectral features in the range of 0.50 to 0.85 microns. Group 3, Kaolinite endmember; diagnostic spectral doublet with minima at 2.17 and 2.21 microns. Group 4, Dolomite endmember; carbonate feature at 2.32 microns. It should be noted that many of the samples in Group 3 also exhibit the goethite spectral features, and that the lone sample in the dolomite group has a strong kaolinite doublet in its reflectance spectrum as well. Table 1 gives a summary of the results of the classification, and Figure 2 exhibits representative spectra from each group.

Group No.	Endmember	Member Samples
1	Basalt	A01; A10
2	Goethite	A03; A11/A14
3	Kaolinite	A05; A06; A07; A08; A09
4	Dolomite	A02

Table 1 - Groups determined from VISIR spectra.

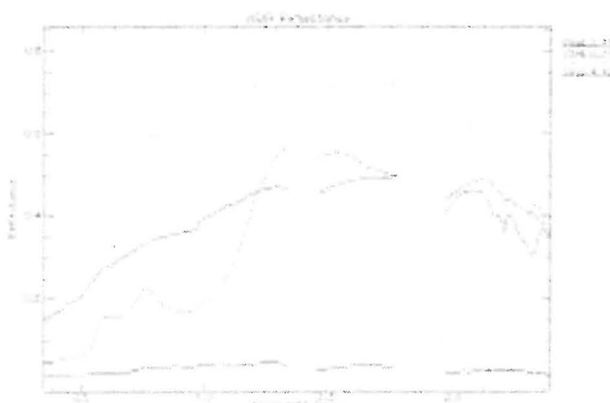


Figure 2 - Representative VISIR reflectance spectra.

The LIBS instrument operates by briefly illuminating a target with a powerful laser pulse that converts a small quantity of the target material to a plasma. This can be done from stand-off distances up to several tens of meters. The plasma that is created radiates in the visible spectrum, and is measurable with a spectrometer. From the spectroscopic data, the elemental composition of the target can be inferred [3].

Due to time constraints, the data acquired by the LIBS instrument in the field consisted only of single shot measurements that were effective over a wavelength range of 370-450 nm. In contrast, the preferred method of data acquisition consists of stacking multiple shots taken from the same target. Also in the interest of time, no in-field composition calibrations were performed. Nevertheless, a great deal of information regarding the abundance of common rock-forming elements was recovered. In all cases, the LIBS data gave relative elemental abundances consistent with the endmembers that were identified from the VISIR reflectance spectra. The LIBS results are given in Table 2. It should be noted that the LIBS analysis was performed without any knowledge of the results from the VISIR spectra.

Combined VISIR/LIBS measurements thus allow for a much more accurate reconstruction of the chemistry and mineralogy of the samples than could be obtained by the analysis of either data set independently. A combined system could be used to great advantage during a rover mission to Mars, remotely acquiring mineralogical and elemental data for a large number of targets during traverses.

	Si	Ca	Fe	Ti	Mg	Al	Sr	Na/ Ca
	Group 1: Basalt							
A01	M	M-H	H	H	H	M-H		M-H
A10	M	M-H	M	M	M-H			M
	Group 2: Goethite							
A03	L	L	H					H
A11	L-M		H		H	L	H	M
A14	L	L	VH		M			
	Group 3: Kaolinite							
A05	VL	M-H			M	L	T	L
A06	VL	M-H			M	L	T	L
A07	M-H		L-M	M-H		M-H		H
A08	M			T		M-H		H
A09	M			T		M-H		H
	Group 2: Dolomite							
A02	VL	M-H			M	L	T	L

Table 2 - Relative elemental abundances from LIBS data. (VH: Very High, H: High, M: Moderate, L: Low, VL: Very Low; T: Trace)

References:

[1] Arvidson R. E. et al. (2000) . [2] Wiens R. C., et al. (2000) LPS XXXI, 1468. [3] Cremers D. A. and Radziemski L. J. (1986) in Laser Spectroscopy and its Applications (L.J. Radziemski, et al., eds), Chapter 5, Marcel Dekker, New York.

THE MYTHS OF MARS: WHY WE'RE NOT THERE YET, AND HOW TO GET THERE. Donna L. Shirley, President, Managing Creativity

This paper is a controversial look at some of the beliefs (myths) held by the space community which block us from formulating a successful Mars Exploration strategy. The origins and consequences of these myths are presented in contrast with attitudes and actions which would have a better chance of getting us to Mars than we currently have.

Some examples of myths:

1. All it takes is guts and leadership:
   a. If a President would just declare.....
   b. If astronauts were willing to take risks.....

1a. was clearly disproved by the result of President George Bush's 1989 speech where he urged the U.S. to "go back to the Moon to stay....."and then on to Mars". Shortly thereafter Congress cancelled all funding not only for human Mars exploration, but also for robotic exploration.

As far as 1b, there are plenty of bold people (test pilots, Everest climbers, bungee jumpers) willing to take the personal risks. However, NASA and the US government have shown no willingness to risk large sums to fund a project (a la Bob Zubrin's Case for Mars) which is perceived to be risky without a compelling reason (e.g. a war).

2. NASA knows best:
   a. Werner was right.
   b. Apollo is the right model.
   c. Only NASA and its contractors (and international partners) can do the job.
   d. NASA <u>is</u> HEDS (Human Exploration and Development of Space).

2a and 2b share the belief that a program focussed solely on getting humans into space for the sake of exploration (or "missile flexing") will be fundable and is the right way to get there. The fact NASA has been unsuccessfully trying that approach since the early 1970's, but failing does not deter many from believing in its inherent correctness as a strategy. (All it takes is guts and leadership.....)

2c. precludes the vast majority of taxpayers from feeling a sense of real participation in the exploration of space, while 2d disenfranchises much of NASA, and especially discounts the role of robotic missions and the possible role of commercial enterprise.

3. If we tell the truth it won't sell
   a. The Shuttle
   b. The Station
   c. The Synthesis Group
   d. Mars Sample Return

MYTHS OF MARS: D. L. Shirley

3 a, b, c and d are all examples of where the cost of the project was either drastically understated or not stated at all. While this worked for the Shuttle and Station, it is unlikely to work for something as vast and visible as human exploration of Mars.

4. Only astronauts are interesting: Examples
   a. The Meatball eats all other NASA logos (except astronaut mission patches)
   b. NASA TV covers every minute of shuttle missions, even when nothing is happening.

The evidence, on the other hand, is that the public is quickly bored with astronauts unless there is something unusual about the mission (e.g. a woman commander or great danger). Whereas the Pathfinder landing and its record-setting web hits demonstrate that even a robotic mission with a gimmick (e.g. a cute rover) and interesting people will attract the public.

5. Scientists know best.
6. International participation saves money.
7. We can't risk astronauts' lives.
8. Etc.

What are some new paradigms that might serve us better in formulating a feasible Mars Exploration program? The following are examples.

1. Tell the truth
   a. About costs
   b. About capabilities
   c. About risk
2. Follow the money
   a. Recognize the power of a jobs program (a la Station)
   b. Nurture commercial and international efforts (but don't oversell them).
   c. Recycle Station components
3. Keep it interesting
   a. Robotic missions with fun stuff – not just good science
   b. Daily, wide-spread pictures, a la Hubble and Chandra
   c. Let other people play – for real! E.g. University student payloads or mission designs – taken seriously.
   d. Pursue more partnerships like Dreamtime.
4. Stay flexible
   a. Set aside some budget for targets of opportunity
   b. Take advantage of new technology – as actually demonstrated, not as "puffed".
   c. Use a "decision tree" program strategy

The paper will flesh out these new paradigms with specific suggestions. An example of a program architecture which reflects these paradigms will be presented.

Advanced THEMIS for Orbital and Landed IR Imaging. S. Silverman[1], K. Blasius[1], and P. R. Christensen[2] [1]Raytheon Santa Barbara Remote Sensing, 75 Coromar Dr., Goleta, CA 93117, [2]Arizona State University, Tempe, AZ 85284,

Introduction: Advanced THEMIS is a project [1] to define and develop to breadboard stage, a miniature infrared imaging radiometer with applications to Mars orbiter and lander missions, as well as other planetary missions. The goal is to maintain or enhance functionality of the Thermal Emission Imaging System (THEMIS) now being built for the 2001 Mars Orbiter while reducing volume by ~75%. Other improvements expected are a broadened spectral range and improved radiometric calibration. A new generation of microbolometer detectors will be tested and further developed. These detectors have a new structure and smaller pitch, 25 microns vs. 50 microns used for THEMIS.

Advanced THEMIS will be a substantially smaller instrument than THEMIS, so it will reduce the cost of multispectral thermal emission imaging on future missions. Candidate missions include Mars Orbiter missions after 2003 and Mars lander-rover missions. The reduction in mass may greatly improve science return from these and other planetary missions. Advanced THEMIS offers opportunities for science return in two areas: surface mineralology and atmospheric phenomena, similar to the Mars Global Surveyor Thermal Emission Spectrometer now in operation [2].

Key Developmental Tasks: The realization of a highly capable Advanced THEMIS for Mars exploration is dependent on the outcome of three project tasks.

1. *Detector Spectral Response Characterization and Design Modifications.* We will characterize the spectral-radiometric response of the new 25μm microbolometer detectors developed by Raytheon Infrared Operations and investigate/implement design changes to improve sensitivity in specific regions of the spectrum. Response will be measured over the spectral range 1.0 to 30 μm.
2. *Detector Noise Characterization.* Uncooled microbolometer detectors have been developed primarily for terrestrial real-time imaging applications. These detectors typically operate at frame rates of either 30 Hz or 60 Hz. The pixel structure has been optimized to have short thermal time. For space remote sensing applications, it is often desirable to increase sensitivity by employing pixel averaging techniques, such as time-delay-and-integration (TDI), for sensors operating in a push-broom scanning mode, or frame-averaging. In either case the detectors must have good 1/f noise characteristics as well as low overall system drift in the output signal. This task will characterize the 1/f noise and output drift of the microbolometer detectors in order to determine the effectiveness of signal averaging.
3. *Radiometric Calibration Approaches.* Absolute IR radiometry requires two-point (gain and offset) calibration, while relative radiometric calibration requires at least single-point (offset) calibration. We will examine a variety of calibration approaches, including internal single and dual temperature references, external single and dual temperature references, partially transparent radiance references, ground truth, and combinations of the above.

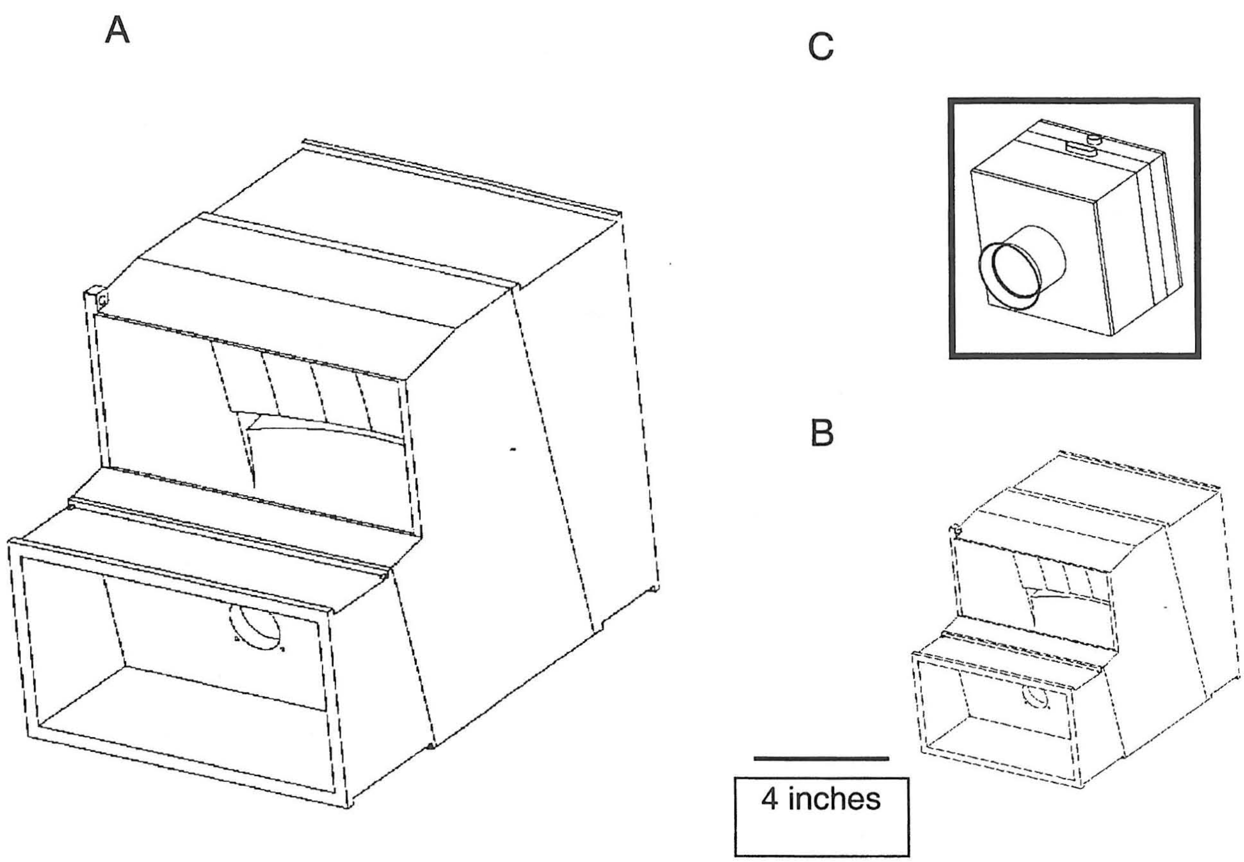
Instrument Concept: Advanced THEMIS is expected to allow future Mars orbiter and lander missions in the post-2003 era to perform multispectral thermal remote sensing of surface materials and atmospheric phenomena with lower launch and spacecraft costs. Table 1 is a comparison of estimated masses of a miniature Advanced THEMIS with THEMIS.

The shown reduction in mass of about 80% would make this Advanced THEMIS suitable for a low mass Mars Orbiter, balloon, aircraft, or rover payload. If only a limited IR spectral range is required, say 7 to 16 μm, and a shorter focal length can meet mission requirements, then the reflective telescope could be replaced with a refractive Ge lens for an additional savings of about 2 lbs. Figure 1. shows a pictorial comparison of THEMIS (A) with Advanced THEMIS concepts using reflective (B) and refractive optics (C).

References: [1] approved for funding in 2000 by NASA's Planetary Instrument Design and Definition Program [2] Christensen, P.R. (1992) JGR, 97, 7719-7734.

Table 1. Mass Budget Comparison Item	THEMIS Lbs.	Advanced THEMIS Lbs.
Refl. Telescope/Housing Assembly	9.7	2.4
Shutter Assembly	0.6	0.05
Electronics, electronics housing, and cables	10.2	1.5
Sunshade	1.6	0.4
Thermal Blankets	1.2	0.3
Misc. H/W, adhesives, etc	0.9	0.2
Total	**24.2 (w/o VIS camera)**	**4.9**

Figure 1. Scale of THEMIS (A) compared to Advanced THEMIS with refractive (C) and reflective (B) telescope optics.



TMBM: TETHERED MICRO-BALLOONS ON MARS. M. H. Sims[1], R. Greeley[2], J. A. Cutts[3], A. H. Yavrouian[4] and M. Murbach[5], [1]NASA Ames Research Center, MS 269-3, Moffett Field, CA 94035, Michael.Sims@arc.nasa.gov, [2]Department of Geology, Arizona State University, Box 871404, Tempe AZ 85287-14045, Greeley@asu.edu, [3]Mars Program Office, Jet Propulsion Lab, 4800 Oak Grove Drive, Pasadena, CA 91109, james.a.cutts@jpl.nasa.gov, [4]Jet Propulsion Lab, 4800 Oak Grove Drive, Pasadena, CA 91109, andre.h.yavrouian@jpl.nasa.gov, [5]NASA Ames Research Center, MS 244-1, Moffett Field, CA 94035, mmurdoch@mail.arc.nasa.gov.

The use of balloons/aerobots on Mars has been under consideration for many years. Concepts include deployment during entry into the atmosphere from a carrier spacecraft, deployment from a lander, use of super-pressurized systems for long duration flights, "hot-air" systems, etc. Principal advantages include the ability to obtain high-resolution data of the surface because balloons provide a low-altitude platform which moves relatively slowly. Work conducted within the last few years has removed many of the technical difficulties encountered in deployment and operation of balloons/aerobots on Mars. The concept proposed here (a tethered balloon released from a lander) uses a relatively simple approach which would enable aspects of Martian balloons to be tested while providing useful and potentially unique science results.

TMBM would be carried to Mars on board a future lander as a stand-alone experiment having a total mass of 1-2 kgs. It would consist of a helium balloon of up to 50 m^3 that is inflated after landing and initially tethered to the lander. Its primary instrumentation would be a camera that would be carried to an altitude of up to tens of m above the surface. Imaging data would be transmitted to the lander for inclusion in the mission data stream. The tether would be released in stages allowing different resolutions and coverage. In addition during this staged release a lander camera system may observe the motion of the balloon at various heights above he lander. Under some scenarios upon completion of the primary phase of TMBM operations, the tether would be cut, allowing TMBM to drift away from the landing site, during which images would be taken along the ground.

The potential return from TMBM includes the following:

Science: Images with resolutions of 5 - 10 cm/pixel would be obtained for the landing site area, providing a critical link between images obtained from the lander and those available from orbit. These images would enable characterization and mapping of features such as small dunes forms, ripples patterns, wind-scours, and other surface structures indicative of the evolution of the Martian surface on sub-meter scales. Analyses of similar features at the Mars Pathfinder site have led to speculation of changes in wind regime through time which might relate to climate change; however, observations are limited in areal coverage and resolution. TMBM would afford the opportunity to test this and similar ideas by providing unique images. We note that images obtained during lander descent could provide similar coverage; however, obscuration by dust raised during descent could significantly degrade image quality. Moreover, the possible use of airbags on landers might make descent imaging difficult or impossible.

Operations: TMBM images would provide a critical base-map for lander operations by giving a context for measurements made from the lander. If a rover is part of the mission, TMBM images would enable planning near-term traverses from science and safety perspectives. The returned images will be mosaicked and structure from motion techniques will be used in the building of 3D terrain models of the landing area.

Technology: Balloons/aerobots of greater capabilities than TMBM could be implemented in further exploration of Mars. TMBM would enable validation of relevant technologies, including approaches and hardware for balloon deployment.

In summary, TMBM would be an excellent low risk addition to any lander mission beginning with the 2003 opportunities.

THE MARTIAN OASIS DETECTOR. P. H. Smith[1], M. G. Tomasko[1], A. McEwen[1], and J. Rice[1], [1]University of Arizona. Tucson AZ 85721, psmith@lpl.arizona.edu.

Introduction: The next phase of unmanned Mars missions paves the way for astronauts to land on the surface of Mars. There are lessons to be learned from the unmanned precursor missions to the Moon and the Apollo lunar surface expeditions. These unmanned missions (Ranger, Lunar Orbiter, and Surveyor) provided the following valuable information, useful from both a scientific and engineering perspective, which was required to prepare the way for the manned exploration of the lunar surface: (1) high resolution imagery instrumental to Apollo landing site selection also tremendously advanced the state of Nearside and Farside regional geology; (2) demonstrated precision landing (< 2 km from target) and soft landing capability; (3) established that the surface had sufficient bearing strength to support a spacecraft; (4) examination of the chemical composition and mechanical properties of the surface.

In terms of Martian exploration, we have achieved (Mariner, Viking, Mars Pathfinder) or are currently gathering (MGS) the following information necessary for Manned Mars Missions: imaging the surface at high resolution, soft landings, established that the surface will support a spacecraft, and conducted a cursory examination of the chemical composition and mechanical properties of the surface. Precision landings need to be achieved as well as surface mobility (10's km). This will be crucial for future unmanned scientific missions, especially sample return. Pinpoint landings and mobility will be required in order to collect the proper samples, i.e. lacustrine sediments, hydrothermal deposits.

Mars has a complex geological and perhaps a biologic history unlike the Moon. New analysis of MGS data indicate that the planet has been active recently in its geologic past (lava flows 10-40 mya, and fresh channels). This will present new but exciting challenges to both the unmanned and manned programs. For instance, a sample return mission will most likely be required to test for any potential harmful affects (chemical and biologic) to humans before sending astronauts. The geologic complexity of Mars, as evidenced in MOC imagery, will not be properly investigated and sampled by robotic missions. Manned expeditions to Mars will have to be conducted in order to fully understand and document the wonderfully complex geology of the surface and subsurface. Additionally, any thorough search for extinct and or extant life will have to be carried out by astronauts. This will involve great surface mobility, flexibility, deep subsurface drilling, and intelligence in the field.

The search for extinct or extant life on Mars will follow the water. However, geomorphic studies have shown that Mars has had liquid water on its surface throughout its geologic history. A cornucopia of potential landing sites with water histories (lakes, floodplains, oceans, deltas, hydrothermal regions) presently exist. How will we narrow down site selection and increase the likelihood of finding the signs of life?

One way to do this is to identify "Martian oases." It is known that the Martian surface is often highly fractured and some areas have karst structures that support underground caves. Much of the water that formed the channels and valley networks is thought to be frozen underground. All that is needed to create the potential for liquid water is a near surface source of heat; recent lava flows and Martian meteorites attest to the potential for volcanic activity. If we can locate even one spot where fracturing, ice, and underground heat are co-located then we have the potential for an oasis. Such a discovery could truly excite the imaginations of both the public and Congress providing an attainable goal for both robotic and manned missions.

The Martian Oasis Detector (MOD): The instrument required to detect an active oasis is a high spatial resolution (few tens of meters) Short Wavelength InfraRed (SWIR) spectrometer coupled with a high resolution camera (5 m/pixel). This combination creates too large a data volumn to possibly return data for the entire Martian surface; therefore, it has been designed as one of the first in a new generation of "smart" detectors.

It works in the following manner. A line of pixels centered on a strong water band is scanned across the surface and ratioed to another line of pixels in the nearby continuum. The results are quickly examined to answer the question: is there an overabundance of water vapor in a tiny spot compared to the local regional water content. In other words, is there evidence for a local source of water vapor? If the answer is yes, then we return all the data from that region as well as a high resolution image boresighted with the spectrometer. These data are then examined on the ground to make a final determination: likely candidates are re-observed to provide further evidence.

Naturally, this instrument can be commanded to fill the allowable data volume on pre-selected targets. It has the ability to detect hydrated minerals, iron oxides, silicates, anhydrous carbonates, evaporites, and ices. The high res imager can similarly improve our knowledge of Martian features. But the unique contribution from this instrument is to find the water.

Detecting water vapor vents: If there is significant geothermal heat reaching the surface of Mars at the present time, there could be local regions where subsurface water is escaping from the surface of Mars at significant rates. The limiting rate is likely to be the rate at which water flows in to replace that lost in evaporation to the atmosphere. Note that the vapor pressure of water can be large compared to the surface pressure on Mars if the water is warm enough to exist in a liquid state just below the surface. The discovery of active vents would provide excellent places to look for signs of past (and possibly present) life on Mars.

Suppose there are small vents where water vapor is escaping into the atmosphere. Let the size of the vent be comparable to the spatial resolution of the SWIR (10s of meters). The column of water vapor will rapidly mix with the CO2 background atmosphere as it rises from the vent. Let the height of the column over which the average water vapor mixing ratio is 50% be H meters. The vertical abundance of water is about 3 cm-amagats per meter of height of the column. For low local wind speeds at the surface, the height H over which the water enhancement persists is likely to be several times the width of the source at the ground. For sources a few tens of meters across, the height H will be many tens to perhaps a few hundred meters. The abundance of water in the column will be 50 to a few hundred cm-amagats.

The background water abundance against which this absorption has to be detected is some 10 precip. μm, for instance, at an air mass factor of 3 at 4:30 pm local time. This corresponds to some 3.7 cm-amagats. Even if the background abundance is 3 times greater, it is much less than that in the water column over a small vent a few tens of meters across.

Figure 1 shows the curve of growth for the 1.38 μm water band for water vapor in the atmosphere of Mars. It shows that the absorption seen in the band is some 2.5% for the background water abundance of 10 precip. μm at an airmass factor of 3, while the absorption is some 10% in a column 100 m tall at 50% mixing ratio (airmass factor of 1) which also includes the backgroundwater vapor. The S/N ratio of the SWIR is 100 in a single pixel, and we can combine 7 pixels at the spectral resolution for which the curve of growth in Fig. 1 is shown. The S/N would be > 250 in the water band. A similar measurement would be made in a nearby continuum region. The absorption could then be measured to better than 150 S/N, so absorptions less than 1% can be measured. It is important for the continuum band close to the wavelength of the water band so that broad features in the reflectivity of the surface do not significantly modify the meaured band/continuum ratio. Fortunately, the reflectivity features in surface materials tend to be much broader than the feature seen in the atmospheric water bands at the low pressures on Mars.

Our plan is to compare the band/continuum ratio measured in individual pixel footprints on Mars with those of other regions across the track of the SWIR and with the running average along the track. When the local ratio exceeds the average ratio by an adjustable threshold factor (perhaps 3), we would trigger collection of an entire SWIR image cube and a high resolution CCD image frame for transmission to the Earth. At other times, the instrument would dump the data, and continue to search.

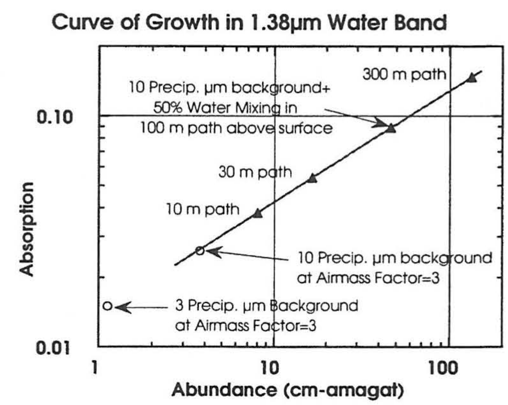


Figure 1. Absorption in 1.38 μm water band at the spectral resolution of the versus water abundance. The abundance of the background atmosphere (some 10 precip. μm at an arimass factor of 3) is shown, as is the total absorption for the background plus a column of 10m to 300m height at an airmass factor of 1 in which the water is mixed at 50% with the CO2 atmosphere. Absorptions of some 10% are seen for columns 100 m high compared to some 1.5% to 4% in case of background atmosphere having 3 to 30 precip. μm water at an airmass factor of 3.

At the present, no instrument has had the ability to detect the one substance that everyone agrees defines the Mars program. The Oasis Detector is the instrument of choice to find the active hydrothermal vents and reignite the Mars program.

What scientific objectives have been defined by the French scientific community for Mars exploration?

Christophe Sotin, chairman of the solar system working group at CNES, Laboratoire de Planétologie et Géodynamique, Nantes, France

Every four or five years, the French scientific community is invited by the French space agency (CNES) to define the scientific priorities of the forthcoming years. The last workshop took place in March 98 in Arcachon, France. During this three-day workshop, it was clear that the study of Mars was very attractive for everyone because it is a planet very close to the Earth and its study should allow us to better understand the chemical and physical processes which drive the evolution of a planet by comparing the evolution of the two planets. For example, the study of Mars should help to understand the relationship between mantle convection and plate tectonics, the way magnetic dynamo works, and which conditions allowed life to emerge and evolve on Earth. The Southern Hemisphere of planet Mars is very old and it should have recorded some clues on the planetary evolution during the first billion years, a period for which very little is known for the Earth because both plate tectonics and weathering have erased the geological record.

The international scientific community defined the architecture of Mars exploration program more than ten years ago. After the scientific discoveries made (and to come) with orbiters and landers, it appeared obvious that the next steps to be prepared are the delivery of networks on the surface and the study of samples returned from Mars. Scientific objectives related to network science include the determination of the different shells which compose the planet, the search for water in the subsurface, the record of atmospheric parameters both in time and space. Those related to the study of samples include the understanding of the differentiation of the planet and the fate of volatiles (including H2O) thanks to very accurate isotopic measurements which can be performed in laboratories, the search for minerals which can prove that life once existed on Mars, the search for present life on Mars (bacteria).

Viking landers successfully landed and the surface of Mars in the mid seventies. Mars Pathfinder showed that rovers could be delivered at the surface of the planet and move around a lander. If it seems feasible that such a lander can grab samples and return them to the lander, a technical challenge is to launch successfully a rocket from the surface of Mars, put in orbit the samples, collect the sample in orbit and bring them back to the surface of the Earth. Such a technical challenge in addition to the amount of scientific information which will be returned, makes the Mars Sample Return mission a very exciting mission at the turn of the millenium. Following the Arcachon meeting, CNES made the decision to support strongly Mars exploration. This program includes three major aspects : strong participation in the ESA Mars Express mission, development of network science in collaboration with European partners, and participation in the NASA-lead Mars Sample Return mission. In addition, participation in micromissions is foreseen to increase the scientific return with low-cost missions.

The Athena Mars Rover Investigation. S.W. Squyres[1], and the Athena Science Team (R.E. Arvidson, J.F. Bell III, M. Carr, P. Christensen, D. Des Marais, T. Economou, S. Gorevan, L. Haskin, K. Herkenhoff, G. Klingelhöfer, A. Knoll, J.M, Knudsen, A.L. Lane, V. Linkin, M. Malin, H. McSween, R. Morris, R. Rieder, M. Sims, L. Soderblom, C. d'Uston, H. Wänke, T. Wdowiak) [1]Cornell University, Ithaca NY 14853.

Introduction: The Mars Surveyor program requires tools for martian surface exploration, including remote sensing, *in-situ* sensing, and sample collection. The Athena Mars rover payload is a suite of scientific instruments and sample collection tools designed to: (1) Provide color stereo imaging of martian surface environments, and remotely-sensed point discrimination of mineralogical composition. (2) Determine the elemental and mineralogical composition of martian surface materials. (3) Determine the fine-scale textural properties of these materials. (4) Collect and store samples. The Athena payload is designed to be implemented on a long-range rover such as the one now under consideration for the 2003 Mars opportunity. The payload is at a high state of maturity, and most of the instruments have now been built for flight.

Imaging and Remote Mineralogy: The topography, morphology, and mineralogy of the scene around the rover will be revealed by *Pancam/Mini-TES*, an integrated imager and IR spectrometer. Pancam views the surface around the rover in stereo and color. The detectors are 1024×512 CCDs, and the electronics provide 12-bit analog-to-digital conversion. Filters provide 14 color spectral bandpasses over the spectral region from 0.4 to 1.1 μm. Narrow-angle optics yield an angular resolution of 0.31 mrad/pixel. Image compression is performed using a wavelet compression algorithm.

The Mini-Thermal Emission Spectrometer (Mini-TES) is a point spectrometer operating in the thermal IR. It produces high spectral resolution (10 cm^{-1}) image cubes with a wavelength range of 6-25 μm, a nominal signal/noise ratio of 450:1, and a maximum angular resolution of 8 mrad (8 cm at a distance of 10 m). The wavelength region over which it operates samples the diagnostic fundamental abscrption features of rock-forming minerals, and also provides some capability to see through dust coatings that could tend to obscure spectral features. The mineralogical information that Mini-TES provides will be used to select from a distance the rocks and soils that will be investigated in more detail and ultimately sampled. Mini-TES is derived from the MGS TES instrument, but is significantly smaller and simpler. The instrument uses an 6.3-cm Cassegrain telescope, a Michelson interferometer, and uncooled pyroelectric detectors. Along with its mineralogical capabilities, Mini-TES can provide information on the thermophysical properties of rocks and soils. Viewing upward, it can also provide temperature profiles through the martian atmospheric boundary layer.

Elemental and Mineralogical Composition: Once promising samples have been identified from a distance using Pancam/Mini-TES, they will be studied in detail using up to three compositional sensors that can be placed directly against them by an instrument arm. The two compositional sensors presently built for flight are an *Alpha-Proton-X-Ray Spectrometer* (*APXS*), and a *Mössbauer Spectrometer*. The APXS is derived from the instrument that flew on Mars Pathfinder. Radioactive alpha sources and three detection modes (alpha, proton, and x-ray) provide elemental abundances of rocks and soils to complement and constrain mineralogical data. The Athena APXS has a revised mechanical design that will cut down significantly on backscattering of alpha particles from martian atmospheric carbon. It also includes a target of known elemental composition that will be used for calibration purposes. The Athena Mössbauer Spectrometer is a diagnostic instrument for the mineralogy and oxidation state of Fe-bearing phases, which are particularly important on Mars. The instrument measures the resonant absorption of gamma rays produced by a ^{57}Co source to determine splitting of nuclear energy levels in Fe atoms that is related to the electronic environment surrounding them. It has been under development for space flight for many years at the Technical University of Darmstadt. The Mössbauer Spectrometer (and the other arm instruments) will be able to view a small permanent magnet array that will attract magnetic particles in the martian soil. The payload also includes a *Raman Spectrometer.* This instrument will provide precise identification of major and minor mineral phases. It requires no sample preparation, and is also sensitive to organics.

Fine-Scale Texture: The instrument arm also carries a *Color Microscopic Imager* that will obtain high-resolution color images of the same materials for which compositional data will be obtained. Its spatial resolution is 30 μm/pixel over a 3-mm depth of field. It uses the same CCD detectors and electronics as Pancam

Sample Collection and Storage: Martian rock and soil samples can be collected using a low-power rotary coring drill called the *Mini-Corer*. This device can obtain intact samples of rock from up to 5 cm within strong boulders and bedrock. Nominal core dimensions are 8×25 mm. The Mini-Corer drills a core to the commanded depth in a rock, shears it off, retains it, and extracts it. It can also acquire samples of loose soil, using a special tool designed for this purpose that can be fixtured to the tip of the drill.

The Mini-Corer can drill at angles from vertical to 45° off vertical. It has interchangeable bits for long life. Mechanical damage to the sample during drilling is minimal, and heating is negligible. After acquisition, the sample may be viewed by the arm instruments, and/or placed in a sample container.

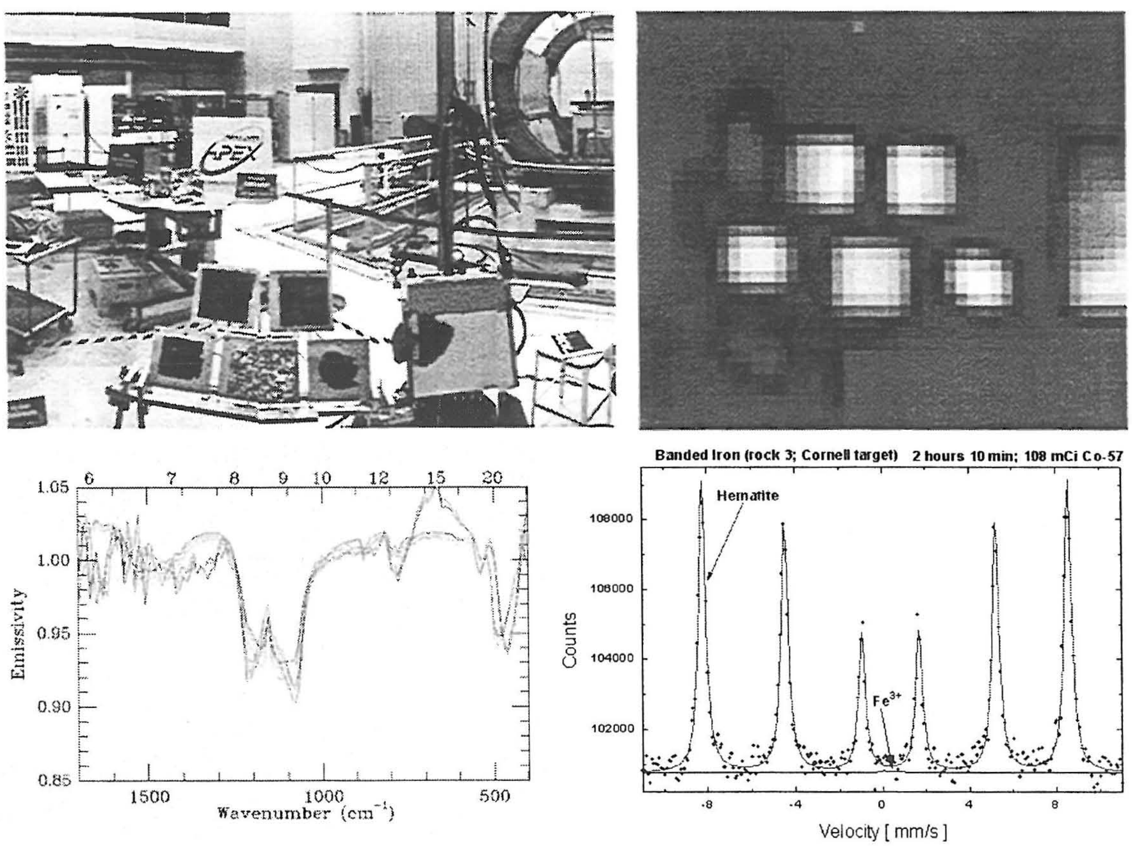
Payload Status: The Athena payload was selected for flight in November of 1997, and has been in development since that time. Flight-qualified versions of Pancam, Mini-TES, APXS, and the Mössbauer Spectrometer have now been built, calibrated, and tested for survival and operation in key flight environments.

The Color Microscopic Imager (CMI) will be built using an existing flight spare Pancam camera body. New optics are now in development for the CMI, as well as a redesigned filter wheel assembly that provides for both color imaging and active focus control.

An engineering model of the Mini-Corer has now nearly completed fabrication. For the Raman Spectrometer, several functional breadboards have been built and have demonstrated good performance. A detailed design for the Raman engineering model has been completed.

Payload Synergy: The Athena payload is specifically designed to be used as an integrated instrument suite. As the rover explores, the in-situ instruments perform detailed analyses of promising samples that are identified from a distance with Pancam and Mini-TES. Selected rocks and soils can then be collected using the Mini-Corer; use of the Mini-Corer also exposes fresh subsurface rock that can be examined by all the instruments. Recent tests have demonstrated the capabilities of the Athena flight instruments. Figure 1 shows some example data.

Figure 1: Data from recent tests of the Athena flight instruments. Cloclwise from top left: (1) Part of a Pancam panorama, showing a rock target in the foreground. (2) A Mini-TES image of the rock target (with a person sitting to the left of it); colors denote mineralogy. (3) A Mossbauer spectrum of one of the targets, showing the signature of hematite. (4) A Mini-TES spectrum of the same target, showing signatures of hematite and quartz.



IN SITU RESOURCE UTILIZATION TECHNOLOGIES FOR ENHANCING AND EXPANDING MARS SCIENTIFIC AND EXPLORATION MISSIONS. K. R. Sridhar[1] and J. E. Finn[2], [1]Department of Aerospace and Mechanical Engineering, University of Arizona, Tucson, AZ 85721; [2]NASA Ames Research Center, M/S 239-15, Moffett Field, CA 94035.

The primary objectives of the Mars exploration program are to collect data for planetary science in a quest to answer questions related to Origins, to search for evidence of extinct and extant life, and to expand the human presence in the solar system. The public and political engagement that is critical for support of a Mars exploration program is based on *all* of these objectives. In order to retain and to build public and political support, it is important for NASA to have an integrated Mars exploration plan, not separate robotic and human plans that exist in parallel or in sequence. The resolutions stemming from the current architectural review and prioritization of payloads may be pivotal in determining whether NASA will have such a unified plan and retain public support.

There are several potential scientific and technological links between the robotic-only missions that have been flown and planned to date, and the robotic + human missions that will come in the future. Taking advantage of and leveraging those links are central to the idea of a unified Mars exploration plan. One such link is *in situ* resource utilization (ISRU) as an enabling technology to provide consumables such as fuels, oxygen, sweep and utility gases from the Mars atmosphere.

ISRU for propellant production and for generation of life support consumables is a key element of human exploration mission plans because of the tremendous savings that can be realized in terms of launch costs and reduction in overall risk to the mission. The Human Exploration and Development of Space (HEDS) Enterprise has supported ISRU technology development for several years, and is funding the MIP and PROMISE payloads that will serve as the first demonstrations of ISRU technology on Mars.

These payloads are critical building blocks toward the future use of ISRU. Many complicated systems, from the collection of atmospheric gases to the liquefaction and storage of propellants must be demonstrated on the Mars surface before they can be built for larger-scale missions. Ground-based testing is necessary and is being performed as completely as possible in simulated Mars environments, but it is not sufficient. There are two reasons for this:

- It is impossible to simulate adequately the environmental conditions on Mars to the degree necessary to achieve the required confidence level. There are many unknowns and variables in the surface conditions that can have a significant impact on the ISRU plant's operation. These include factors such as the physical, chemical, and electrical properties of dust; atmospheric composition; the diurnal temperature characteristics; the heat transfer environment; wind velocities; and the various weather cycles and patterns.

- An ISRU-based architecture will be a mission-critical element. It is simply inconceivable that a mission-critical element that has not been tested in the *real* environment will ever be baselined for a mission — robotic or human. Technology demonstrations of mission-critical elements are not a luxury, they are a necessity. The Thomas Young Committee report succinctly captures this philosophy by stating "test-as-you-fly, fly-as-you-test."

Clearly, flight demonstrations of ISRU technology are needed prior to human missions. How can such technologies benefit earlier, robotic science missions? There are several ways:

- Sample return.
- Power for surface mobility (roving and aerial vehicles).
- Nighttime heat and electricity production (regenerative fuel cells).
- Deep drilling projects.
- Utility and sweep gases for experiments.
- Science will demand that humans go to Mars.

In our discussion and presentation at the workshop, we will highlight how the PROMISE ISRU experiment that has been selected by HEDS for a future Mars flight opportunity can extend and enhance the science experiments on board.

FIELD EXPERIMENTS WITH PLANETARY SURFACE ROVERS: LESSONS FOR MARS MISSION ARCHITECTURE.
Carol Stoker, NASA Ames Research Center, M.S. 245-3, Moffett Field, CA 94035, cstoker@mail.arc.nasa.gov

Introduction: Over the last decade, a variety of field experiments have been performed that simulate operations of a rover on Mars [1,2,3,4,5,6]. These, in combination with the Pathfinder experience, lead to a realistic assessment of rover mission capabilities and to recommendations for rover technology and mission architecture to improve the science return of Mars exploration.

Table 1 summarizes field experiments that represent a range of possible mission designs and operational strategies. The experiments varied by the type and quality of imaging systems and other instrumentation, the use of orbital and aerial imaging and spectroscopy, the communication bandwidth and command strategy, and the distance traveled. All mission simulations were blind field tests operated by science teams whose interpretations were compared to field ground truth providing an assessment of the accuracy of remote science interpretations and a better understanding of where improvements are needed.

Table 1. Capabilities demonstrated on rover field experiments

Experiment	Orbital Data	Aerial Data	Rover Imaging	Rover Instruments	Ops. style	Comd. Cycles	Traverse Distance
Kilauea, 1995[1]	b&w 10m/pix	aerial over-flight (film + prints)	color streaming video, frame-grab	arm camera	real time teleop.	NA	1.2 km (in 8 hrs)
Tuba City 1996 [2]	b&w 10m/pix	simulated descent (film + prints)	multispec. stereo 1mrad/pix	arm camera, sample scoop	single command, rapid feedback	70 (in 3 days)	100m
Pathfinder 1997 [3]	Viking,b&w >100m/pix	none	b&w. stereo 3mrad/pix	APX	command sequence, lander spots rover	80 (in 90 days)	100m
Silver Lake 1999 [4]	b&w 10m + 2m/pix, multispectral images (VNIR& TIR 10 m/pix)	simulated descent (b&w, digital images)	color stereo .3mrad/pix	VNIR spectra, TIR spectra, RAC	command sequence	16 (in 14 days)	40m
LunarCrater 2000	b&w 10m/pix	simulated descent (color digital images), AVARIS	color stereo .3mrad/pix	none	command sequence	12 (in 3 days)	60m

2001 Mission Field Test: One relevant mission simulation was performed in Silver Lake, California in 1999 (SL99)[4] using the Marsokhod rover. The payload (Descent Imager, PanCam, MiniTES, and Robotic Arm Camera), rover size and capabilities, data volumes, and command cycles simulated those planned for the Mars Surveyor mission originally selected for 2001which included a rover carrying the Athena payload [7] and a lander carrying a robotic arm and Robotic Arm Camera system [8]. The field rover carried a high resolution (.3mrad/pixel) color imager which simulated the Athena PanCam. A visible/near-infrared (VNIR) fiberoptic spectrometer (operating range 0.35-2.5μm), bore-sited with the left PanCam imager and an infrared spectroradiometer (operating range 8-14 μm) simulated the MiniTES Thermal Emission Spectrometer from the Athena payload. An engineering model of the Robotic Arm Camera selected for the 2001 lander was also used in conjunction with the excavation of a trench into the subsurface. The science team was provided with simulated images from the Mars Descent Imager selected for the 2001 lander, simulated Mars Orbiter Camera (MOC) images, and multispectral images similar to those expected from the 2001 orbiter THEMIS instrument obtained with the airborne Thermal Infrared Mapping Spectrometer. Commands sequences were sent daily to the rover and data returned were limited to 40 Mbits per communication cycle. Figure 1 shows the science sites visited during this simulation, referenced to a simulated MOC-resolution oribtal image. During the 14 day simulated mission, 16 commands were uplinked to the rover, it traversed ~ 40 meters, 6 sites were analyzed, 11 samples were collected for laboratory analysis, and over 5 Gbits of imaging and spectral data were collected. Remote science interpretations from 22 participants were compared with ground truth from the field and laboratory analysis of collected samples.

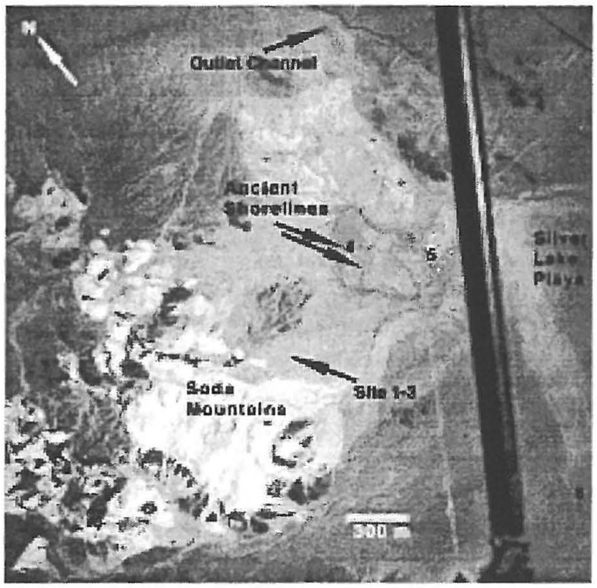


Figure 1. Field site for SL99 test. Sites 1-6 were visited during the mission simulation. Sites 1-3 were on an alluvial fan at the flank of the Soda Mountains. Sites 4-5 were on ancient shorelines of Silver Lake.

Using this payload and mission approach, the science team synergistically interpreted orbital data, descent imaging, rover imaging and infrared spectra, and microscopic imaging of a trench to deduce a consistent and largely correct interpretation of the geology, mineralogy, stratigraphy, and exobiology of the site. Use of imaging combined with infrared spectroscopy allowed distant source outcrops to be correlated with local rock. Different lithologies were distinguished both near the rover and at distances of hundreds of meters or more. Subtle differences such as a contact between dolomite and calcite were identified at a distance of 1/2 km. A biomarker for endolithic microbiota, a plausible life form to find on Mars, was successfully identified. Microscopic imaging of soils extracted from the surface and subsurface allowed the mineralogy and fluvial history of the trench site to be deduced.

Recommendations for Mars Architecture: Conclusions and recommendations derived from the field experiments follow.

1. The scientific productivity of SL99 shows that this payload and mission approach has high science value and would contribute substantially to achieving Mars exploration goals. Thus, the mission payload originally selected for 2001 is scientifically valid and should be flown. Even though the simulation made limited use of mobility (only 40 m were actually traversed by the rover) the science productivity of the payload was considerable. A stationary 2001 lander carrying this payload would do good science.

2. Rover mobility is severely limited by the command strategy, power sources, and navigation approaches formerly in the Surveyor program baseline. Rovers are unlikely to travel more than 10 m in a command cycle in smooth terrain, and significantly less if there are obstacles. Short duration missions (a few months) are thus unlikely to travel more than a few hundred meters and possibly much less. Limited mobility is useful for exploring site diversity, but ideally science is served by mobility on the scale of kilometers. Increasing rover operational range will require improved onboard navigation technology, use of a referenced positioning system (e.g. GPS) for increased traverse accuracy, more frequent commanding, and/or longer-lived missions.

3. Limitations on rover mobility would be less important if accurate landing site targeting could be performed. Improvements in entry, descent, and landing approach to produce targeting uncertainties of 1 km or less should be pursued.

4. Technologies should be developed to enable longer range mobility than rovers can achieve. For example, a ballistic hopper or airplane with take off and landing capability could provide point to point mobility to explore specific features of interest.

References: [1] Stoker, C., *J. Geophys. Res.,* **103**, 28557, 1998. [2] Christian, D. *et al., 1997 Field and Service Robotics Conference*, Australian Robotics and Autonomy Assoc., Canberra, Australia, 1997. [3] Golombek, M. P., *et al., J. G. R.*, **104**, 8523, 1999. [4] Stoker, C. *et al., J. G. R.* in press, 2000. [5] Cabrol, N. et al., *J. G. R.* in press, 2000. [6] Arvidson, R.E. *et al., J. G. R.,* **103**, 22671-22688, 1998. [7] Squyres,S.W., *et al.,* The Mars 2001 Athena Precursor Experiment (APEX), *LPSC 30*, 1672, 1999. [8] Keller, H.U. *et al.,* The MVACS Robotic Arm Camera, *J. G. R.,* in press, 2000.

***IN SITU* NOBLE-GAS BASED CHRONOLOGY ON MARS.** T. D. Swindle, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092. tswindle@u.arizona.edu

Determining radiometric ages *in situ* on another planet's surface has never been done, and there are good reasons to think that it will be extremely difficult [1]. It is certainly hard to imagine that such ages could be measured as precisely as they could be measured on returned samples in state-of-the-art terrestrial laboratories. However, it may be possible, by using simple noble-gas-based chronology techniques, to determine ages on Mars to a precision that is scientifically useful.

This abstract will 1) describe the techniques we envision; 2) give some examples of how such information might be scientifically useful; and 3) describe the system we are developing (under a PIDDP grant), including the requirements in terms of mass, power, volume, and sample selection and preparation.

Techniques: By determining the abundances of major and minor elements in a sample, heating that sample to release noble gases trapped within it, and then analyzing the abundances of the isotopes of the three lightest noble gases (He, Ne, and Ar), two different types of ages can be determined.

Since one of the naturally occurring isotopes of potassium (K) decays to ^{40}Ar, the abundances of potassium and ^{40}Ar can be used to determine a K-Ar age. This gives the time since the sample was last heated enough to release Ar (several hundred degrees C). For terrestrial samples, metamorphism often resets some, but not all, of the minerals within a rock, so the ^{40}Ar-^{39}Ar technique has largely superseded the K-Ar echnique. On Mars, K-Ar ages are likely to date the crystallization of the rock, unless it has experienced a long or unusual impact history. K-Ar ages are likely to be measurable for martian samples ranging in age from a few million years old to the age of the planet.

The other type of age that can be determined is a cosmic-ray-exposure (CRE) age. Bombardment of any rock by cosmic rays will produce a wide variety of nuclei, including those of the noble gases, by "spallation" nuclear reactions. Since the surface of Mars is only partially shielded from cosmic rays, these cosmogenic nuclides will build up in any rock that is within about 1 meter of the surface. If the abundances of the target elements (basically, the major and some minor elements in the rock) and the cosmic-ray-produced noble gases are measured, and the production rate can be calculated, this gives the length of time the sample has been at the surface. If many samples on a surface have the same exposure age, that age probably represents the age of the surface itself. CRE ages are likely to be measurable from about 100,000 years to a few tens of millions of years. These measurements also give the radiation dose that a sample has experienced, which could be valuable information for quarantine considerations.

Examples: We believe the system described below can measure K-Ar and CRE ages with a precision of about 10%. This leads to two questions. First, are there places on Mars where an age with that precision would be scientifically useful? Second, would the ages determined by those techniques be interpretable in terms of martian chronology?

There are at least two types of terrain on Mars where 10% precision ages would be valuable. 1) Although the relative ages of various surfaces have been determined by crater counts, the absolute ages are very poorly known. Various estimates of the ages of some surfaces encompass virtual the entire history of the planet (e.g., the Late Hesperian-Early Amazonian boundary is anywhere from 0.6 to 3.5 Ga [2]). A single set of K-Ar ages from a suitable surface could pin down the entire cratering curve. 2) Determining the ages of the youngest volcanic or fluvial events would be of immense interest, and could be done by determining CRE ages (and, in the case of volcanics, K-Ar ages) from the surface.

A major concern with the K-Ar system is whether trapped martian ^{40}Ar, from either the mantle or the atmosphere, could lead to erroneous ages. As a first test of how meaningful K-Ar ages might be, Table 1 compares K-Ar of martian meteorites with the crystallization ages of those meteorites [3], using data from

Table 1: K-Ar ages of martian meteorites

Meteorite	Crystallization Age (Ga)	K-Ar Age (Ga)	Ref.
ALH84001	4.51(11)	4.1	3
Chassigny	1.34(5)	1.32(7)	3
		1.46(17)	6
Nakhla	1.27(1)	1.30(3)	7
		1.1(3)	8
		1.4(3)	8
Lafayette	1.32(3)	1.36(3)	7
G. Valadares	1.33(1)	1.34	9
Shergotty	0.165(4)	.14-0.40	3
ALH77005	0.178(6)	0-3.6	3
EET79001B	0.173(3)	0-1.9	3
QUE94201*	0.327(10)	0-0.66	3
Y790327	0.212(62)	0-1.9	3
Zagami*	0.177(3)	0.15-0.24	3

Uncertainty in last digit(s) given in parentheses
* Feldspar separate

the literature for the K-Ar ages. In the shergottites, which contain measurable trapped Ar for other isotopes, trapped ^{40}Ar has been corrected for by assuming a trapped $^{40}Ar/^{36}Ar$ ratio of 200-1900, which encompasses likely values for the mantle and atmosphere [4]. For the other meteorites, the listed K-Ar ages are values reported in the literature. The only old sample (ALH84001) gives a K-Ar age slightly (roughly 10%) younger than its crystallization age, presumably reflecting later impacts. Four intermediate-aged samples give K-Ar ages indistinguishable from their crystallization ages. The six youngest samples all have a significant amount of trapped ^{40}Ar. Only two of them give demonstrably non-zero ages. However, these ages, while uncertain to much more than 10% because of the corrections that have to be applied, do agree with the crystallization ages. Hence the meteorites all give ages that either agree with the crystallization ages (to 10% or the uncertainty, whichever is larger), if they give ages at all. Furthermore, it is possible that a large fraction of the trapped argon in the shergottites was implanted by the impact that ejected the meteorites from Mars, so *in situ* measurements might be less affected by trapped Ar.

There should be little doubt that CRE ages could determine the age of a surface. The technique has already been used to determine the ages of young lunar craters in the vicinity of the Apollo landing sites (e.g., Cone, North and South Ray Craters) [5]. CRE ages have also been used for terrestrial surfaces, but in terrestrial applications, larger samples and higher precision measurements are required than will be necessary for Mars, where the cosmic-ray flux is roughly 1000 times higher.

Proposed system: Under a PIDDP grant for which funding has just started, we are developing a system that can determine noble-gas-based ages *in situ* at 10% precision, using components developed through other programs by three different laboratories. The system is summarized in Table 2. Basically, we used Laser-Induced Breakdown Spectroscopy (LIBS) to measure elemental abundances, an oven modified from MPL TEGA to heat the samples, and a miniature quadrupole mass spectrometer array to measure the noble gases. All of the component parts have been developed with spacecraft applications in mind, so all are miniaturized. The ovens will be significantly redesigned from TEGA. Since we do not need to perform calorimetry, but do need higher maximum temperatures, the requirements for that part of the system will change (mass and volume will certainly become smaller, we expect power consumption to remain the same or decrease). Note that the subsystems operate sequentially, so the total power required is the maximum power for any individual subsystem.

The system would determine K-Ar and CRE ages (both could be determined on each sample) on 12 samples of a few milligrams each. It assumes that material will be provided in the form of powder (e.g., from a drill), from within rocks at a site than has been characterized well enough to know where in martian stratigraphy it falls, and whether there are nearby large impact craters that could be affecting ages. Note that the LIBS analysis guarantees a chemical analysis of the sampled rock. Since the ages determined will be much less accurate than what could be done with a returned sample, we suspect that our system will be more valuable on an *in situ* mission than a sample return mission. However, it could provide help in sample selection or radiation verification for a sample return.

Acknowledgments: This work is supported by PIDDP Grant NAG5-9198.

References: [1] Swindle T.D. et al. (1996) *Planetary Surfaces Instruments Workshop* (LPI/TR 95-05), 21-40; [2] Tanaka K.L. (1986) *Proc. LPSC 17th*, in *JGR* 91, E139-E158; [3] Nyquist L. E. et al. (2000) *Evolution of Mars* (ISSI), submitted; [4] Bogard D.D. and Garrison D.H. (1999) *Meteoritics & Planet. Sci.* 34, 451-473; [5] Arvidson R. et al. (1975) *Moon* 13, 259-276; [6] Lancet M.S. and Lancet K. (1971) *Meteoritics* 6, 81-84; [7] Podosek F.A. (1973) *EPSL* 19, 135-144; [8] Ganapathy R. and Anders E. (1969) *GCA* 33, 775-787; [9] Bogard D.D. and Husain L. (1977) *GRL* 4, 69-71.

Table 2: *In situ* geochronology system

Subsystem	**Developer(s)**	**Mass (kg)**	**Power (W)**	**Volume (cm^3)**
Elemental analyzer (LIBS)	D. Cremers, LANL	1.4	2.3	1400
Oven (TEGA)	W. Boynton, LPL	5.7	60	4000
Mass spectrometer (QMSA)	A. Chutjian and M. Darrach, JPL	1.8	12	2150
Total		8.9	60	7150

Other Science Team members: D. Kring (LPL), S. Baldwin (Syracuse)

NEXT-GENERATION ENTRY/DESCENT/LANDING SYSTEM FOR MARS LANDERS. S. W. Thurman[1]
[1]Jet Propulsion Laboratory, California Institute of Technology, M. S. 264-440, 4800 Oak Grove Dr., Pasadena, CA 91109-8099. (E-mail:sam.w.thurman@jpl.nasa.gov).

Introduction: Many important scientific objectives for Mars exploration require the ability to land safely at select sites. The "first-generation" entry, descent, and landing (EDL) systems used in previous missions imposed limitations on target site selection due to the delivery accuracy achievable and those systems' inability to recognize and avoid hazardous terrain. This abstract outlines key capabilities of a proposed second-generation EDL system, currently under development by a consortium of NASA centers, industry, and academic institutions.

EDL System Description: An illustration of a representative system concept is provided in Fig. 1 below. The entry capsule pictured is being designed for both direct entry, as has been done in the recent *Mars Pathfinder* and *Mars Polar Lander* missions, or delivery into the atmosphere from orbit, if it is desired to carry the spacecraft into orbit prior to landing. Hence, carrier vehicle options range from a cruise stage to an orbiter spacecraft with a mission of its own.

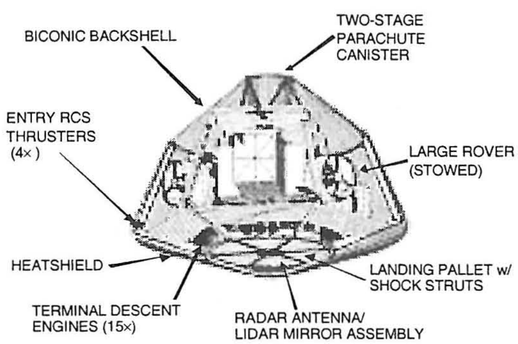


Figure 1: Entry Capsule Cutaway View

The entry capsule is designed to accommodate potentially large (600-1000 kg) payloads while providing aeromaneuvering capability for closed-loop guidance to within ± 3 km (3σ) or better of a designated target site. A biconic backshell is used to obtain high volumetric efficiency in payload packaging (a large rover is shown in Fig. 1 as an example). A two-stage parachute system is employed, enabling deceleration of very large spacecraft while allowing time for terminal sensing and hazard avoidance during terminal descent. Both radar and lidar sensors are used for local terrain-relative navigation to identify safe landing sites to the spacecraft's guidance system.

The touchdown event itself is made robust as possible to any residual terrain hazards. Figure 1 shows one example of a robust landing approach; a pallet-type structure augmented with webbed shock struts to help prevent tip-over. This scheme and other alternatives are discussed further by Rivellini.[1]

The architecture of this system is structured not only to incorporate current sensor technology and guidance/navigation logic, but also to readily accommodate future capabilities as warranted. Examples of potential future additions include the capability to perform onboard radio navigation via orbiting spacecraft or surface beacons, and guided parachute descent for "pinpoint" delivery to a designated target site.

EDL Sequence of Events: The key events occurring during entry, descent, and landing are illustrated in Fig. 2. This figure also provides approximate values of the altitude, velocity, and timing of each event for a representative direct entry mission.

Approach Phase (not shown). Prior to entry the spacecraft must be guided to the target entry corridor. The spacecraft's own propulsion system and guidance system are capable of doing so, or the entry capsule may be augmented with an external propulsion system if desired, controlled by the onboard guidance system.

Entry/Atmospheric Deceleration Phase. Once the spacecraft begins to encounter the atmosphere, its entry guidance logic is activated. The guidance system computes bank angle commands to steer the capsule's lift vector such that the correct parachute deploy conditions will be achieved at a desired position relative to the target landing site. This guidance scheme is a derivative of the Apollo entry guidance approach,[2] and has been tested extensively in a high fidelity simulation environment[3] for use at Mars.

Parachute Descent Phase. Deployment of the supersonic parachute is triggered by the entry guidance logic at approximately Mach 2.2. This parachute is a derivative of the *Mars Pathfinder* mortar-deployed parachute, and serves as a drogue parachute in this EDL system, decelerating the spacecraft quickly to subsonic speeds. Once the vehicle reaches Mach 0.8, the backshell and supersonic parachute are jettisoned (eliminating mass that is no longer needed), and a much larger (up to 30 m) subsonic main parachute is deployed. This parachute is designed to quickly bring even large vehicles to low (40-50 m/s) terminal velocities that provide sufficient time for terminal sensing prior to powered descent.

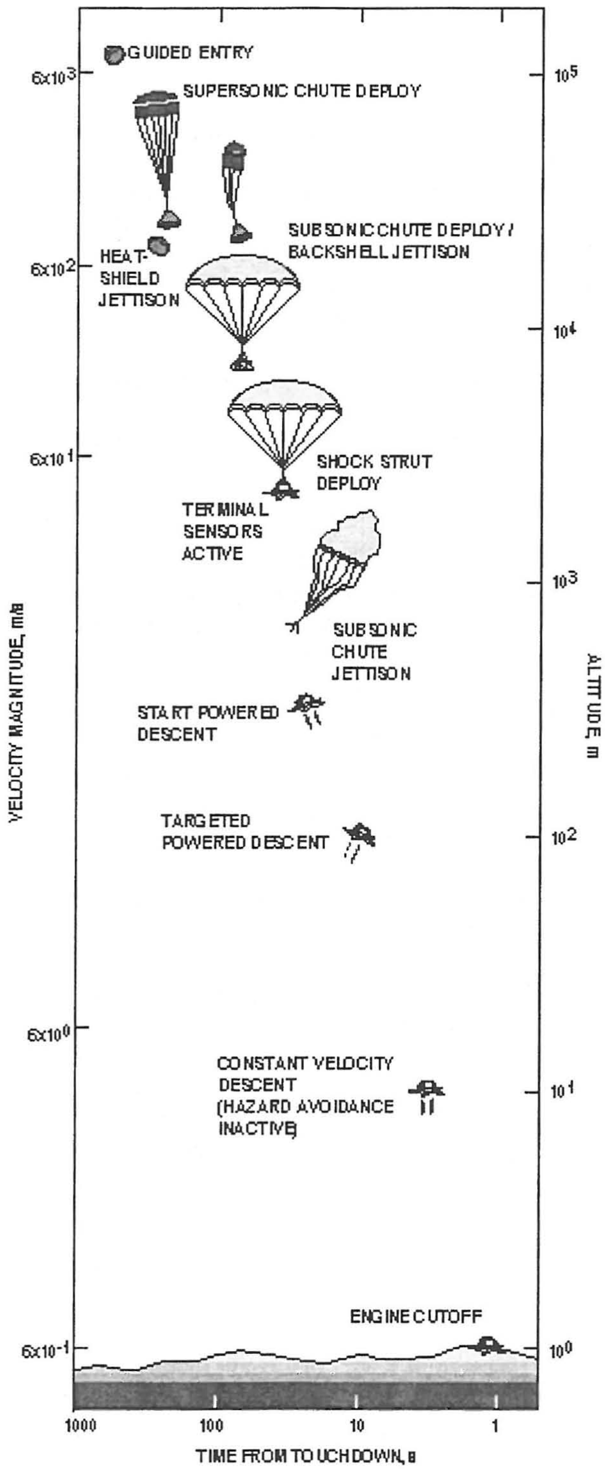


Figure 2: EDL Sequence of Events

During parachute descent terrain-relative navigation is initiated. The landing radar acquires the surface at an altitude of 3700 m, allowing the onboard navigation system to accurately determine the spacecraft's surface-relative altitude and velocity. In the 1500 to 1000 m range a scanning lidar begins periodically generating local elevation maps of the surface, in the area surrounding the guidance system's current projected landing site. The lidar elevation maps are used within the guidance system to identify any potential hazards near the projected site, and to redesignate the target site to a safer location if necessary.

Powered Descent Phase. Once the navigation system and hazard identification logic have designated a safe, and reachable, local target site, the lander's guidance system computes an appropriate time to separate from the subsonic parachute and begin powered descent. This computation establishes a trajectory that will reach the designated target site while maximizing the amount of available performance margin.

The radar and lidar sensors, along with the hazard detection and retargeting logic, continue to operate during powered descent, scrutinizing the target site and the surrounding area as the effective resolution of the lidar-generated terrain maps improves, redesignating the target site as needed. The guidance system periodically computes a new reference trajectory leading to the current target site, using a set of algorithms derived from the powered descent guidance logic for the Apollo Lunar Module.[4]

Touchdown. Powered descent concludes with thrust termination approximately 1 m above the surface, resulting in velocity components at touchdown of approximately 3 m/s (vertical) and a tolerance of ±0.5 m/s (horizontal), well within the capabilities of the landing/arrest approaches under consideration.

Development Plan: Prototype development and test activities for new system components have already been initiated, including a prototype lidar/hazard detection system, subsonic parachute, and aerodynamic implements for hypersonic maneuvering.

Acknowledgements: The author would like to recognize the contributions of EDL team members at NASA's Ames Research Center, Moffet Field, CA, Johnson Space Center, Houston, TX, and Langley Research Center, Hampton, VA, along with the Naval Air Warfare Center at China Lake, CA. The work described in this abstract was carried out, in part, at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References: [1] Rivellini, T. P., Oritz, G. M. and Steltzner, A. D. (2000) LPI Workshop, Houston, TX. [2] Carman, G. L., Ives, D. G. and Geller, D. K. (1998) AIAA Atmospheric Flight Mechanics Conf., Boston, MA, No. 98-4570. [3] Striepe, S. A., Queen, E. M., Powell, R. W., Braun, R. D., Cheatwood, F. N., Aguirre, J. T., Sachila, L. A. and Lyons, D. T. (1998) AIAA Guidance, Navigation, and Control Conf., Boston, MA, No. 98-4569. [4] Klumpp, A. R. (1974) *Automatica, 10,* 133-146.

Ensuring radiation safety for Mars-bound astronauts. R. E. Turner ANSER, Suite 800, 1215 Jefferson Davis Hwy, Arlington, VA 22202, (turnerr@anser.org)

Introduction: Human expeditions to Mars will be the most ambitious space missions of our time. To execute these missions successfully, the radiation environment must be understood and risks appropriately managed from a systems perspective [1,2,3]. Mars exploration missions from 2001 through the next twenty years present exciting and unique opportunities for advances in radiation risk management of a future human mission to Mars. A major HEDS objective is to characterize the Martian radiation environment. In addition, the Mars mission cruise phases provide multipoint observations of SPEs in the critical region of the heliosphere (1 to 1.5 AU) needed to reduce the in-flight radiation risk to a future Mars-bound crew. To enable the incorporation of appropriate instrumentation, it is critical that the Mars exploration roadmap continue to recognize the importance of energetic particle detectors and radiation monitors on landers, orbiters, and during the cruise phase.

Physics background: It is generally accepted [4,5] that there are two classes of SPEs, each with distinct signatures and broad characteristics. Impulsive flares may produce particle events that are electron-rich, relatively short-lived (hours), and generally limited to within a 30-degree longitude band about the nominal field line connected to the active region. Gradual particle events by contrast are proton-rich, long-lived (days) and may be spread over a broad range of solar longitudes, in some cases over 180 degrees.

The very large SPEs that pose a risk to astronauts fit in the "Gradual Event" category. They are produced by the shock associated with fast CMEs [6,7,8]. For a fast CME, particle acceleration begins as the shock forms in the solar corona and continues as the shock moves out into the interplanetary medium. Energetic particles immediately stream out along the magnetic field lines to 1 AU. As the shock expands, it crosses other field lines, accelerating particles as it goes, and, within tens of minutes of shock formation, particles are flowing outward over an extremely broad front. Maximum acceleration occurs near the nose of the shock, ahead of the CME, and the intensity falls off around the flanks of the shock. As the structure propagates outward, the successive magnetic field lines that connect an observer with the shock sweeps counterclockwise across the shock's surface, averaging over diverse shock conditions.

Need for additional observations: A complete picture matching the physics of particle acceleration to the detailed observation of any one event is very difficult due to the inherent three dimensional nature of the event, our lack of distributed observations, and the complex nature of the underlying processes occurring near the sun during CME production and within the ambient solar wind [9]. There are many things going on nearly simultaneously, and several of them may either be directly related to the production of large SPEs, or sufficiently correlated to act as proxies to tag an ongoing event as likely to produce a significant SPE. Some SPEs have a secondary peak flux that occurs with the passage of the shock ahead of the CME. There is little observational data on the spatial and temporal variation of this shock-enhanced peak.

The need for correlated observations has been recognized by several workshops convened to examine SPE risk mitigation strategies [eg., 10,11]

Recognizing this need, a workshop established to determine Mars radiation measurement objectives for the Mars 2001 mission recommended surface measurements of radiation exposure, correlated with orbital measurements of the input flux. As a secondary objective the workshop endorsed the need to measure the radiation dose and radiation quality onboard the spacecraft en route to Mars [12].

Surface and orbital measurements: Despite the lack of a significant magnetic field, the thin atmosphere (one percent of the thickness of Earth's atmosphere) may provide adequate shielding to protect the astronauts on the Martian surface from SPE radiation, even under minimal spacesuit thickness. Simonsen, et al., 1990 [13], modeled the dose equivalent from exposure to GCR and SPE at a range of Martian elevations (0 to 12 km). The GCR exposure varied from 10 to 18 cSv, while SPE exposure varied from 10 to 30 cSv. Note that the annual BFO guideline of 50 cSv is approached at high altitudes. Recent investigations, which more carefully incorporated backscattered neutrons, suggest the dose equivalent may be higher than initially estimated [14]. *In situ* radiation monitors, as originally planned for the Mars 2001 mission, must obtain more information about the radiation levels at the Martian surface for a variety of altitudes and a range of subsurface conditions to validate models.

Cruise phase measurements: Through the nine or so months in transit, instrumentation on Mars-bound spacecraft would have the potential to observe multiple solar particle events. The cruise phase of orbiter -lander pairs provide unique opportunities to increase our understanding of the acceleration mechanisms for energetic solar particles by providing multipoint *in situ* measurements of the environment. These measurements can be correlated with near-Earth-based observations of solar activity and particle flux. Detailed interpretations of the data will also consider differences in solar latitude and distance from the Sun.

Ensuring radiation safety for Mars-bound astronauts. R. E. Turner

Potential Instruments: The MARIE instruments on the Mars 2001 lander and orbiter were designed to measure the energetic particle background and the secondary particles generated in the Martian atmosphere and on the Martian surface. The combination of orbiter and lander measurements was to provide particle flux above and below the Mars' atmosphere to validate transport codes to correlate with dose measured by the lander. The orbiter instrument consists of a particle spectrometer that can measure the energy spectra of charged particles over energy range of 15-450 MeV/n. The lander carried a smaller particle telescope, and two proportional counters.

During the cruise phase, the lander and orbiter instruments can be exposed to the interplanetary environment. When not in conflict with cruise phase operations, both instruments can be powered to collect and store data. The data can be time-tagged and relayed to Earth periodically.

It is important that the sensors are sensitive to the energy range of ten to a few hundred MeV and can sustain a count rate of 10^4/s-sr-cm^2. Appropriate instruments can be low mass (less than five kilograms) and low power (a few watts) as demonstrated by NASA's STEREO mission. JPL studies [15] have demonstrated the feasibility of similar instruments in small deep space micromissions with total spacecraft mass of 15 kilograms. Such spacecraft could be elements of secondary of missions of opportunity.

Correlation with Space Physics Missions: Mars missions can be complementary to planned space physics missions, such as Stereo, and proposed Living With a Star missions, particularly the Sentinel mission which is intended to observe CMEs and SPEs over distributed heliolongitudes *inside one AU*. The Mars program provides the opportunity to extend these important measurements *out to 1.5 AU*.

Conclusions: Surface measurements of the Mars radiation environment, correlated with orbital measurements of the incident flux, provide the only way to validate models of radiation exposure for future human missions. Since the surface flux will vary with Martian altitude and with subsurface composition, these measurements are best made at multiple surface locations over varied geography and altitude.

Coordinated launches of two or more spacecraft to Mars during recurring periods of favorable Earth/Mars alignment, along with near-Earth observations of solar activity and particle flux, provide unique opportunities to advance our understanding of SPEs. Multipoint observations of energetic particle flux will provide insight into the acceleration mechanism and the evolution of SPEs. This in turn will support efforts to reduce the risk these events pose to humans in space.

References:

[1] Striepe, S., J. Nealy,, and L. Simonsen, Radiation exposure predictions for short-duration stay Mars missions, *J. of Spacecraft and Rockets*, Vol. 29, No. 6, 801-807, November-December 1992.

[2] Striepe, S., J. Nealy,, and L. Simonsen, Radiation exposure predictions for long-duration stay Mars missions, *J. of Astronautical Sciences*, Vol. 42, No. 2, 131-142, April-June 1994.

[3] Turner, R. and J. Levine, Orbit Selection and Its Impact on Radiation Warning Architecture for a Human Mission to Mars, Acta Astronautica, Vol. 42, Number 1-8, 411-417, 1998.

[4] Miller, J., Hudson, H., and Reames, D. *EOS* V46.n41 10 October 1995.

[5] Cane, H., R. E. McGuire, and T.T. von Rosenvinge, *Astrophys. J.*, 301, 448-459, 1986.

[6] Cane, H., *Coronal Mass Ejections — Geophysical Monograph 99,* AGU, Washington D.C., 1997.

[7] Reames, D., *Coronal Mass Ejections — Geophysical Monograph 99,* AGU, Washington D.C., 1997.

[8] Kahler, S., *Astrophys. J.*, 428:837-842, 1994.

[9] Lee, M. *Coronal Mass Ejections — Geophysical Monograph 99,* AGU, Washington D.C., 1997.

[10] Turner, R. ed., Foundations of Solar Particle Event Risk Management Strategies...Findings of the Risk Management Workshop for Solar Particle Events, ANSER, Arlington, VA, July 1996.

[11] *Proceedings of Workshop: Impact of Solar Energetic Particle Events for Design of Human Missions,* Center for Advanced Space Studies, 3600 Bay Area Boulevard, Houston, Texas, September, 1997.

[12] *Proceedings of the Radiation Monitoring on Mars Workshop,* USRA, Houston, TX, Feb 1997.

[13] Simonsen, L., J. Nealy, L. Townsend, and J. Wilson, Radiation Exposure for Manned Mars Surface Missions, *NASA Technical Paper 2979*, 1990.

[14] Clowdsley, M.S., J.W. Wilson, M.Y. Kim,R.C. Singleterry, R.K. Tripathi, J.H. Heinbockel, FF. Badavi, J.L. Shinn, Neutron Environments on the Martian Surface, 1st International Workshop on Space Radiation Research and 11th Annual NASA Space Radiation Health Investigators' Workshop, Arona, Italy, 27-31 May 2000.

[15] Collins, D. H., Multimission Space and Solar Physics Microspacecraft, JPL report IAA-L-1110, Pasadena, CA.

CCD-based XRD/XRF for Determining Environmental Mineralogy on Mars. D. T. Vaniman[1], D. L. Bish[1], D. F. Blake[2] and S. J. Chipera[1], [1]Los Alamos National Laboratory, Geology and Geochemistry, MS D462, Los Alamos, NM 87545 (vaniman@lanl.gov), [2]NASA Ames Research Center, Mail Stop 239-4, Moffett Field, CA 94035.

The Need for Understanding Environmental Mineralogy on Mars: Health effects from Martian dusts will be a concern for any manned Mars missions. Nuisance dusts plagued the Apollo astronauts [1], but dusts of more hazardous mineralogy, in habitats occupied by Mars astronauts weakened by a long-duration mission, may be more than a nuisance. Chemical hazards in Martian regolith attributable to S, Cl, Br, Cd, and Pb are known or strongly suspected to be present [2], but terrestrial studies of the health effects of dusts indicate that accurate determination of mineralogy is a critical factor in evaluating inhalation hazards [3]. Mineral inhalation hazards such as the Group-1 carcinogenic zeolite erionite, which is demonstrated to cause mesothelioma, cannot be identified by chemical analysis alone. Studies of palagonite analogs raise the possibility that erionite may occur on Mars [4].

In addition to health effects concerns, environmental mineralogy has significant importance in resource extraction, groundwater use, and sustained agriculture. The high sulfur and chlorine content of Martian regolith will affect all of these uses, but the nature of mineralogic reservoirs for S and Cl will determine their uptake and concentration in extracted groundwater and in agricultural applications of regolith. Wet chemistry experiments planned for the Mars Environmental Compatibility Assessment (MECA) will define some of the consequences of water/soil interaction [5], but an understanding of the mineralogic basis for water-rock reactions is needed to understand the mechanisms of reaction and to apply the results of a few experiments to larger scales and different conditions.

Methods for Determining Environmental Mineralogy in Space: The value of chemical data for soil analysis has been proven by the Mars Viking and Pathfinder surface landers. Although the data obtained have been meager, they have provided useful constraints on our current understanding of the Martian surface. However, chemical data alone leave serious gaps in our understanding of a planet such as Mars since a single chemical composition may represent a wide range of mineral assemblages and complex minerals may form in combination with H, S, and halogens. The mineralogy, which is much more critical to planetary surface science than simple chemical composition, will remain unknown or will at best be imprecisely constrained unless the minerals present can be identified unambiguously.

Diffraction is the technique of choice for mineralogical analysis in terrestrial laboratories. X-ray diffraction (XRD) is a direct and accurate analytical method for determining mineral species; data obtained by XRD are fundamentally linked to crystal structure, the basic factor in determining a mineral identification. We have developed laboratory XRD methods that recognize occurrences of hazardous minerals such as erionite in abundances well below 500 ppm [6].

Most of the ambiguous mineral identifications obtained with remote spectral sensing (*e.g.*, visible and IR spectra) can be resolved by XRD. Additional chemical data, obtained by XRF, can greatly improve the interpretation of complex samples. Several concepts for combined XRD/XRF have been proposed in the past decade, using a variety of configurations. The concept we summarize here is based on the CHEMIN instrument, which uses a single CCD detector for both XRD and XRF analysis. A detailed description of the prototype CHEMIN instrument is provided in [7]; that reference emphasizes the use of CHEMIN in Martian exobiology studies but the basic concept is applicable to a wide range of mineralogic investigations.

CCD-based XRD/XRF Instrumentation for Environmental Mineralogy: The traditional and well-tested method of definitive mineral identification by XRD has not been used on any planetary surface other than Earth. CHEMIN, which was developed to address this deficiency, uses transmission geometry and a CCD detector in single-photon counting mode to discriminate between diffracted and fluoresced X-rays on the basis of energy. The CCD detector in the current design is 1 cm^2 and could be incorporated in an instrument of ~500 cm^3, weighing <1 kg and operated at ~2 W [7].

Conventional laboratory methods for XRF and XRD analysis use fine powders or fused samples (for XRF). Production of such samples is labor intensive and would be difficult to automate for remote applications. However, appropriately designed robotic XRD/XRF systems can be optimized to handle poorly powdered samples. This is particularly important in XRD analysis, where "spotty" diffraction patterns from poorly prepared or natural powders (*i.e.*, poor particle statistics) present problems in most conventional diffraction configurations. The CHEMIN CCD configuration is designed to measure entire Laue diffraction rings below ~35° 2θ, thereby compensating for poor powder preparation, such as might be produced by robotic sampling systems. The spotty Laue rings are not a problem in the CHEMIN configuration because the system collects ~100 times the data used in conventional detector systems. Circumferential integration removes much of the uncertainty introduced by spotty diffraction rings, and the quality of the Laue rings provides information about grain size (spottiness diminishes markedly at grain sizes <10 μm and rings become smooth as grain size diminishes to ~5 μm).

Figure 1 shows a CHEMIN diffraction pattern for poorly powdered celestite ($SrSO_4$), one of many members in the complex family of ~1750 S-bearing minerals, several of which could be present in Martian rocks or regolith. Although visibly spotty, integration of the Laue rings on this pattern produces a plot of diffracted intensity versus 2θ that can be used easily with advanced data reduction techniques such as the Rietveld method. We have tested CHEMIN with many pure minerals and mineral mixtures to examine its potential in mineralogic exploration of extraterrestrial bodies. Rietveld refinement methods were applied to XRD data to provide unit-cell parameters and quantitative phase information from ~1-mg sized samples. Good refinements were obtained with pure minerals or simple mineral mixtures, and trace calcite (1.6%) and quartz (0.2%) were readily identified in an aragonite sample. Because of limited diffraction resolution, results were poorer with complex mixtures such as basalt, although refinements yielded reasonable results. This limitation can be overcome if a CCD with more pixels than the prototype CCD (512x512) is used. In addition, CHEMIN analyzes a very small amount of powder, which illustrates the advantageous sensitivity of the CCD detector, although this feature may limit accuracy with some samples due to sample statistics (*i.e.*, too few grains analyzed). Small sample size, however, will not be a problem where fine-grained regolith or eolian samples are analyzed and particularly where the respirable size fraction (≤10 μm) is of principal concern.

Sampling of Martian Regolith: Natural powders and dusts occur on most planetary surfaces, including Mars. The optimum crystallite size for XRD of minerals with Cu Kα radiation is on the order of 1-10 μm and sizes up to ~100 μm are often suitable. Mars Pathfinder experiments point to the existence of at least some soils of <40-μm grain size [8] and eolian accumulations on spacecraft surfaces had grain sizes of <2 μm with compositions representative of the bulk soil [9]. Both materials are important targets for analysis; eolian deposits carry information that can be used to infer regional compositions far beyond the range of a rover, and analyses of soils provide information on weathering processes. In addition, both soils and eolian dusts must be considered in terms of inhalation hazards, impact on Mars-base environmental systems, and resource utilization.

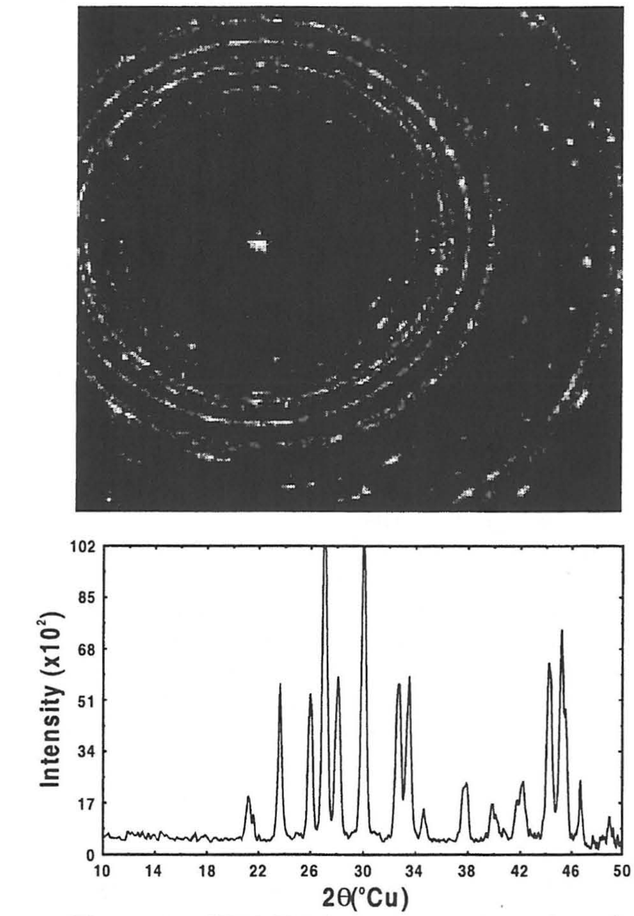


Figure 1. CHEMIN diffraction pattern of poorly powdered celestite, showing the spotty diffraction rings from large crystallites in the sample, and the smooth pattern of intensity versus 2θ obtained by circumferential integration of the diffraction rings.

References: [1] Heiken G. H. et al. (1991) *Lunar Sourcebook: A User's Guide to the Moon*. Cambridge Univ. Press, N.Y. [2] Newsom H. E. and Hagerty J. J. (1997) *JGR, 102,* 19,345-19,355. [3] Guthrie G. D., Jr., and Mossman B. T. (eds.) (1993) Health Effects of Mineral Dusts, *Rev. Min., 28*, MSA. [4] Golden D. C. et al. (1993) *JGR, 98*, 3401-3411. [5] Grannan S. M. et al. (1999) *LPI Contribution No. 991*, 41-42. [6] Bish D. L. and Chipera S. J. (1991) *Clays & Clay Min., 39*, 437-445. [7] Vaniman D. et al. (1998) *JGR, 103,* 31,477-31,489. [8] Matijevic J. R. et al. (1997) *Science, 278*, 1765-1767. [9] Hviid S. F. et al. (1997) *Science, 278*, 1768-1770.

POTENTIAL ATMOSPHERIC AND BIOMARKER MEASUREMENTS ACQUIRED BY *IN SITU* INSTRUMENTATION ON MARS J. H. Waite[1], D. S. Bass[1], D. T. Young[2], and G. P. Miller[1] [1]Southwest Research Institute (P.O. Drawer 28510 San Antonio, TX 79228-0510 hunter@kronos.space.swri.edu), [2]University of Michigan (Space Physics Research Laboratory, 2455 Hayward Street, Ann Arbor, MI 48109-2143 dtyoung@umich.edu).

The use of *in situ* measurements on the Martian surface: 1) can greatly improve our ability to select sample return materials with high scientific potential and 2) can be used to study the climate history of Mars. In this paper we discuss the principals of sample preparation, gas chromatography, mass spectrometry, and related techniques that can achieve the measurement objectives described in a companion abstract. Here we also discuss an investigation we have undertaken in coupling of a mass spectrometer to a differential scanning calorimeter such as that developed by the University of Arizona for the Mars Polar Lander MVACS payload.

Atmospheric Measurements. The detection of compounds in the parts-per-billion (ppb) to parts-per-quadrillion (ppq) level is a considerable technical challenge even for the most sensitive of instrumental techniques currently available. In light of the severe resource constraints imposed on lander instruments we have concluded that pre-concentration of the evolved gas prior to its introduction into the mass spectrometer presents the most practical method to achieve the enhancement in sensitivity necessary for accurate chemical characterization of evolved compounds.

The gas sampling and concentration system for organic and inorganic volatile species is based on a proven design for adsorption of these gases here on Earth. It will create a concentrated water sample in order to obtain minor species and oxygen abundances by using an adsorbent with H_2O selective properties. Several additional adsorbents for organic and inorganic volatile compounds will also be employed. The sorbent materials are reversible upon heating so that sampling and measurement can be repeated using a single concentration device.

The gas sampling system is coupled to a high-sensitivity electron bombardment ion source and either a time-of-flight mass spectrometer or a magnetic deflection cycloidal mass spectrometer, depending on resource constraints

Surface/Subsurface Measurements We have undertaken a study to investigate a low power, low mass integrated prototype soil analyzer capable of performing thermal gas analysis. The instrument package will be capable of accurately determining the thermal phases of volatiles, minerals, and the chemical composition of their evolved gases. It is comprised of a soil processor, differential scanning calorimeter, a tunable diode laser spectroscopy system, and a mass spectrometer. We are prototyping the coupling of the UA thermal and evolved gas analyzer to several different mass spectrometry designs, including a time-of-flight (TOF) mass spectrometer and a cycloidal mass spectrometer.

Organic Biomarker Measurements Extraction techniques for a large number of organic molecules bound in soil or in a rock matrix are well developed. The analysis of soil and rock cores for specific biomarkers is used by the oil industry to help identify potentially oil rich deposits. The general technique involves the extraction, cleanup, concentration followed by analysis. Extraction techniques make use of slightly polar organic and sometimes inorganic solvent systems such as supercritical CO_2 with a polar organic modifier such as methanol. The efficiency of extraction is generally better than 80% for most compounds. The most difficult step in the process is the cleanup of unwanted interferant compounds that are coextracted in the extraction step of the process. This generally requires passing the sample at low pressure through columns packed or coated with adsobents that will selectively retain the interferant compounds allowing the compound of interest to pass through the device, recovered and concentrated for analysis.

There has been widespread interest in recent years to develop extraction and isolation techniques using microfluidic MEMS devices to deliver reagents to extract, cleanup and separate components of interest by use of on-line microdialysis [1]. These postage stamp sized microfluidic "laboratory on a chip" devices require microliter volumes of reagents, can easily be interfaced to mass spectrometers, are sufficiently small that several devices can be integrated onto a single package for redundancy and can deliver a concentrated sample using small volumes. The use of microfluidics in combination with capillary electrophoresis has allowed post column derivitization of chromophores to improve detection by UV/VIS for compounds that do not have functional groups that absorb at these wavelengths. Techniques have also been developed for the addition of reagents that promote electrospray ionization of organic compounds followed by mass spectral analysis.

The incorporation of microfluidic MEMS devices used for the extraction, cleanupand concentration of biomarkers and other organic compounds of interest appears to be a promising approach to follow considering the limited resources available on landers. The analysis of these compounds by mass spectrometry after extraction and cleanup from the sample matrix can be performed by a variety hyphenated techniques that include but not limited to GC/MS, Matrix Assisted Laser Desorption Ionization (MALDI), Secondary Ion Mass Spe trometry (SIMS) and Plasma Desorption Mass Spectrometry (PDMS). MALDI is a soft ionization laser desorption technique with minimum fragmentation of the parent ion that can be performed utilizing a low power laser (diode laser). The technique involves the mixing of the extract with a organic compound that has high absobance efficiency for the laser radiation. This results in the ionization of the compound from a surface after a short duration laser pulse is focused which is ideal for time-of-flight mass spectrometers whose extraction pulse can be synchronized with the laser pulse. In SIMS, a primary gun of neutral or charged atoms such as argon or xenon is focused on a surface containing the analyte. The primary beam ablates the matrix containing the analyte ionizing the analyte in the process into the mass spectrometer for analysis.

Plasma desorption mass spectrometry utilizes a radioisotope such as Californium that undergoes spontaneous fission. The fission-fragment induced ionization is highly efficient soft ionization that preserves molecular weight information and since the ionization occurs from a plane (all ions having nearly identical starting times) is ideal for high resolution time-of-flight mass spectrometry.

Both subsurface and atmospheric detection of methane gas is also of general interest. The low molecular weight of methane combined with its low abundance presents similar problems as do the noble gases for enrichment. The use of graphitized carbon blacks coated on molecular sieve materials are useful for trapping this compound. Soil samples can be heated and the effluent directed to a small trap containing this material for enrichment. Air samples can be obtained by pumping a volume of atmosphere through the trap. Methane can then be thermally desorbed onto the head of a gas chromatography column for separation from other gases also trapped and analyzed by mass spectrometry or a thermal conductivity detector

[1]Naxing Xu *et al.* (1998) *Proc. 46th ASMS Conf. On MS and Allied Topics*, May 31-June 4, 1998, FL.

The Athena Raman Spectrometer Alian Wang[1], Larry. A. Haskin[1], Bradley Jolliff[1], Tom Wdowiak[2], David Agresti[2], Arthur L. Lane[3], and the Athena Science Team. [1]Washington University, Dept. Earth & Planetary Sciences, St. Louis, MO, 63130, [2]University of Alabama at Birmingham, Dept. Physics, Birmingham, AL, 35294, [3]Jet Propulsion Laboratory, Pasadena, CA, 91109

Introduction: Raman spectroscopy provides a powerful tool for *in situ* mineralogy, petrology, and detection of water and carbon [1,2,4,5,]. The Athena Raman spectrometer is a microbeam instrument intended for close-up analyses of targets (rock or soils) selected by the Athena Pancam and Mini-TES. It will take 100 Raman spectra along a linear traverse of ~1 cm (point-counting procedure) in one to four hours during the Mars' night. From these spectra, the following information about the target will extracted: the identities of major, minor, and trace mineral phases, organic species (e.g., PAH or kerogen-like polymers), reduced inorganic carbon, and water-bearing phases; chemical features (e.g. Mg/Fe ratio) of major minerals [6]; rock textural features (e.g., mineral clusters, amygdular filling and veins). Part of the Athena payload, the miniaturized Raman spectrometer has been under development in a highly interactive collaboration of a science team at Washington University and the University of Alabama at Birmingham, and an engineering team at the Jet Propulsion Laboratory. The development has completed the brassboard stage and has produced the design for the engineering model.

Instrument characteristics The miniaturized Raman spectrometer consists mainly of two parts: a probe deployed by a robotic arm, and a source-spectrograph unit consisting of the laser, detector, electronics, and microprocessor, all located within the warm electronic box of the rover. The excitation laser beam and collected Raman signal are transmitted via optical fibers. The Raman probe has a scanning mechanism to enable linear traverses. The 532 nm line of a diode-pumped solid state laser is used as the excitation source. The laser delivers a condensed, ~10 mW beam (~25μm in diameter) onto the sample. The spectrograph covers two spectral regions: 200-1700 cm^{-1} (for oxides, oxyanions, and carbonaceous materials) and 2500-4000 cm^{-1} (for hydrogen bonded to O, C, N, S). It has a spectral resolution of 6-7 cm^{-1} and a peak position accuracy of ~1cm^{-1}. A point-counting measurement procedure was designed to take spectra from original surfaces of rocks or soils and from the distal ends of samples obtained by coring. As the target surface will be uneven, the sampling objective has an 8 mm working distance. The instrument needs no auto-focusing mechanism, because the optical design [3] enables a depth-of-sampling range for strong Raman scatters of ≥2.5 mm. The total mass of the system is ~2.5 kg, of which the probe is ~220 g. A maximum of 36 Watt-hours is required per set of 100 Raman spectra. The size of the brassboard is ~5.5 × 7.5 × 7.7 cm for the probe, and ~16.4 × 15.9 × 7.7 cm for the spectrograph.

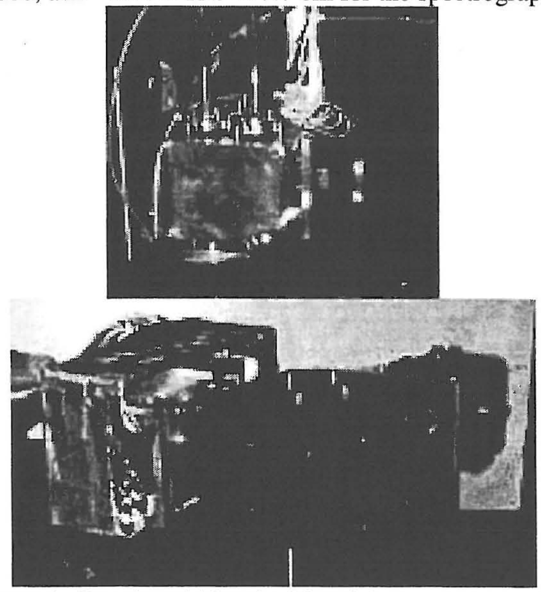


Figure 1. Brassboard 1d probe (above) & spectrograph.

Brassboard models performances: Extensive performance tests have been done on all breadboard and brassboard models. Overall, they have proved highly successful, demonstrating that a Raman spectrometer can be built that is suitably miniaturized and low enough in power for use as an on-surface planetary instrument, yet retains high detection sensitivity and yields laboratory quality spectral resolution over a broad wavelength range. These features are essential to provide accurate mineral characterization.

Raman spectra obtained by using brassboard 1b on three common igneous minerals are shown in Fig. 2. Reduced carbon of probable organic origin is readily identified from the spectra of two ancient cherts (Fig. 3). The detection of carbonate and sulfate minerals is especially important, since they are potentially important indicators of ancient Mars environments and evidence of past water activity. Raman spectra of some natural carbonate and sulfate minerals obtained using brassboard 1d appear in Fig. 4. These spectra demonstrate that mineral classification (i.e., silicate, carbonates, sulfates) can often be achieved by mere inspection of raw spectra, and that chemical features of individual mineral species are revealed by detailed Raman parameters such as peak positions.

The Athena Raman Spectrometer: L. A. Haskin, Alian Wang, B. L. Jolliff, T. Wdowiak, D. Agresti, and A. L. Lane

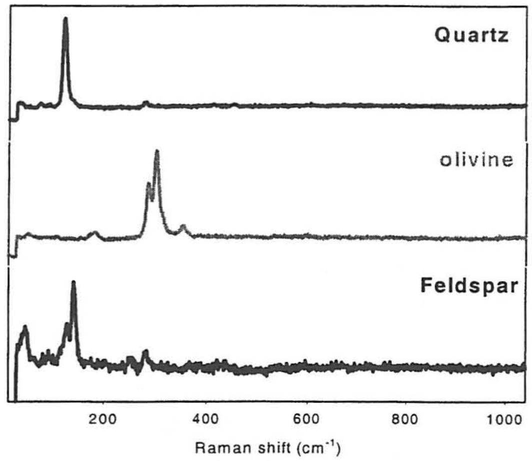


Figure 2. Raman spectra obtained by brassboard 1b from common igneous minerals

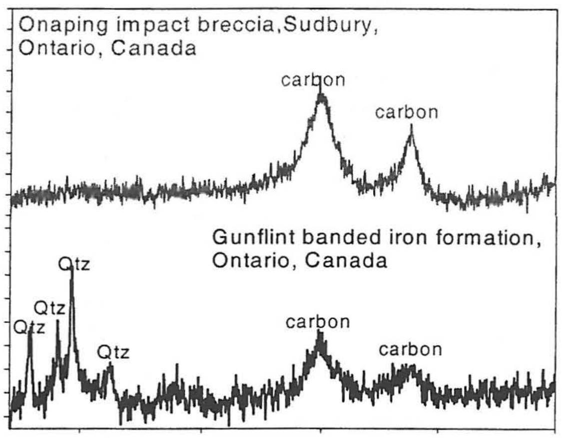


Figure 3. Raman spectra obtained by brassboard 1b from two ancient cherts

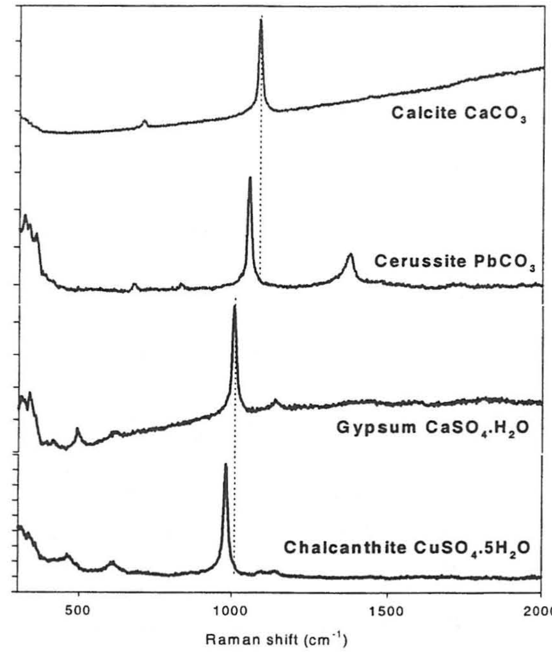


Figure 4. Raw Raman spectra obtained by brassboard 1d from natural carbonate and sulfate minerals

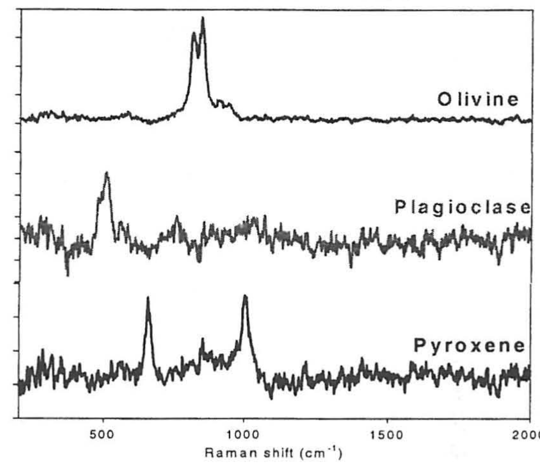


Figure 5. Raman spectra obtained by using brassboard 1d from a volcanic rock sample.

The sensitivity of the brassboard 1d model was tested briefly at low laser power and untweaked alignment by a 20-point traverse across the surface of a terrestrial basalt. Figure 5 shows three of the Raman spectra obtained. Of 20 spectra taken from this random sampling, 15 yielded identifiable peaks. Further detailed tests of the brassboard are planned.

References: [1] Wang, A. et al., Raman spectroscopy as a method for mineral identification on lunar robotic exploration missions, *J. Geophys. Res.*, 1995. 100: p21189-21199. [2] Haskin, L. A. et al., Raman spectroscopy for mineral identification and quantification for in-situ planetary surface analysis: a point count method, *J. Geophys. Res.*, 1997. 102: p19293-19306. [3] Wang, A. et al., A Raman spectroscopic sensor for in situ mineral characterization on planetary surface. *Appl. Spectrosc.* 1998. 52: p477-487. [4] Wang, A. et al., Raman spectroscopic characterization of a Martian SNC meteorite: Zagami. J. Geophys. Res., 1999. 104: p8509–8519. [5] Wang, A. et al., Raman spectroscopic characterization of a highly weathered basalt: igneous mineralogy, alteration products, and a microorganism, J. Geophys. Res., 1999. 104: p27067 -27077. [6]. Wang A., et al., Characterization of structure and compositions of quadrilateral pyroxenes by Raman spectroscopy -- implication for future planetary exploration, *XXXI LPSc*, 2000, #1875.

IN-SITU INSTRUMENTATION FOR EXOBIOLOGICAL OBJECTIVES ON MARS: DEVICES, PROTOCOLS AND STRATEGIES. T. J. Wdowiak, Astro and Solar System Physics Program, Department of Physics, University of Alabama at Birmingham, Birmingham, AL 35294-1170 <wdowiak@uab.edu>.

Introduction: The "life" issue is the most provocative driver for the exploration of Mars, therefore several dicta are necessary. These are:

- Prior to specific "life search" activities it is imperative that understanding Mars as a planet, particularly its ancient nature, is a first condition.
- Proper instrumentation for serving exobiological objectives must be first capable of producing high level planetary science. Highly specialized instruments must be avoided, particularly those of the "test strip" variety. The mistake of the "life search" instrumentation package of the Viking missions must not be repeated
- Instrumentation that elucidates molecular structure is highly suited for both high level planetary science and exobiology objectives
- The most desirable architecture is one that organizes several instruments into an integrated suite to maximize tasking - create "an orchestra"
- The NASA SP-530 "An Exobiological Strategy for Mars Exploration" remains an excellent basis for planning

For the past decade the Astro and Solar System Physics Program of the University of Alabama at Birmingham (UAB) has been engaged in the definition and development of planetary surface instruments directed toward exobiological objectives. Experience with the miniaturization of both Mössbauer and Raman spectrometers, developing an impact tool that is the equivalent of a geologist's rock hammer for robotic obtaining of fresh surfaces, and currently addressing how to do time-of-flight mass spectroscopy on Europa has resulted in a perspective that is, for the most part, one of undertaking instrumentation development to meet scientific objectives rather than tailoring prior interests to "fit in". Since May 1997 considerable effort has been expended in the development of the Athena Raman Spectrometer which is a joint project of Washington University, UAB, and JPL.

Available Instruments: Currently a number of specific instruments have already been developed in conjunction with the Mars Polar Lander and the '01 Athena Precursor Experiment/'03 Athena Rover effort. These exist in the forms of advanced breadboards, engineering models, and flight hardware. Given the expense, and more importantly the time invested, it would seem to make good sense to utilize this now-available technology at least in the '05-'07 launch time frame. The instruments have sufficient compatibility, particularly the Athena items, to be arrangeable into integrated instrumentation suites where performance characteristics overlap and importantly permit in-situ verification of results. In particular it should be understood that the Athena Raman Spectrometer, a near-ready development at the engineering model stage, is the first available instrument that permits unambiguous identification of mineralogy and carbonaceous materials at the microscale level (~25 micron), which is incredibly important for understanding the nature of a composite material, namely a rock! As a molecular structure directed probe, it is fully capable for detection of H_2O and hydroxyl components in all forms. From the standpoint of planetary science it does both the analysis of igneous, sedimentary, and metamorphic minerals as not only stand-alone species, but on the level of microcrystals in rocks. Should carbonaceous inclusions exist in a sample, the microscale capability permits detection at very low whole rock concentrations. It is quite likely that carbonaceous material, if present will be as inclusions rather than being dispersed. This capability, and the current state of development, makes the Athena Raman Spectrometer an ideal instrument of choice for both in-situ exploration and selection of samples for transport to Earth. In the '05-'07 launch time frame it makes sense to consider any instrument suite delivered to Mars to be in the category of a "facility" system available to a community of participants selected through the peer review process.

Desirable Instruments: When looking beyond the '05-'07 launch time frame two requirements come immediately to mind: 1) capability for interrogating samples extracted from subsurface depths and the interiors of rock masses (outcrops or large pieces of ejecta); and 2) isotope abundance determination. Both of these are formidable objectives given the economics of transport of systems likely to be more massive and energy consumptive than the "couple of kilograms and a few watts" that is the present realistic constraint. It should be pointed out that a "lunar drill" although contemplated, was never taken to the Moon even though the LEM vehicle was considerably larger than what will be available for Mars. The best alternative to a "Mars drill" is to seek out specific pieces of ejecta that can be traced back to a specific crater and utilize smaller core extraction systems to obtain interior samples. Of course shock metamorphism will be an issue; however, lessons of terrestrial impacts ought to be applicable in the interpretative process. Integration of the terrestrial impact research community into Mars exploration will be important.

The isotope abundance determination issue is going to be largely dependent upon developing laser technology that permits conversion of console-size mass spectrometers to miniature flight instruments. Also other means of isotope determination such as plasma spectroscopy need to be explored. This kind of effort could draw upon heritage of uranium isotope separation technology developed over the past three decades and based upon tunable lasers. The optogalvanic effect is a possible detection technique. Cavity-ring down spectroscopy makes possible the spectroscopic detection of very sparse species including hydrocarbons, but again we are looking at a 10-year time frame to achieve a flight instrument.

Recommendation: Save money by utilizing the instruments already "in the pipeline" for at least the '05 and '07 time frame, and invest in the development of new miniaturized instrument technologies for use in the second decade of this century. Also be prepared to accept new technology advances that will come from the non-space community. Remember Raman spectroscopy as an in-situ flight technique wasn't feasible until ~1995.

Acknowledgement: The research that served as the basis for this discussion was made possible by the privilege of a succession of grants from the Planetary Instrument Definition and Development Program (PIDDP), the Athena Rover Integrated Science Project, and the Astrobiology Program.

Life on Mars: What and Where?

Frances Westall, Lunar and Planetary Institute, Houston.

The search for life on Mars has gathered momentum since McKay et al's [1] publication concerning possible life in a martian meteorite. In this contribution, I present my opinion of what to look for and where based on my own studies of fossil bacteria in the context of the early history of life on Earth. My premise is that the search for extraterrestrial life needs to take place within a planetary context. I first analyse what is known about the context for the origin of life on Earth and what we understand about the first fossil organisms. Then I will briefly compare the early terrestrial environment to that of Mars. Finally I will consider what to look for in the search for life on Mars, and likely environmental locations.

Early Earth

Evidence from basalts from almost the entire history of the Earth indicates that the mantle was oxidised (at least back to Isua times, ca. 3.8 b.y. [2] and possibly back as far as 4.3 b.y. [3]). This implies recycling of hydrated crust which, in turn, implies the presence of surficial water, such as oceans, as well as a tectonic recycling mechanism, such as plate tectonics. Some of the volatiles (water as well as organics) may have come from cometary and asteroid input [4]. The pre-4.3 b.y.-old mantle was essentially dry. Early recycling and melting of crust to produce at least some sialic differentiation is demonstrated by the existence of the Acasta Gneisses (4.1-4.0 b.y.-old) which, themselves, are derived from both hydrated, depleted mafics as well as earlier granitoids [5]. The oxidated state of the mantle precluded the emission of reducing gases from about 4.3 b.y., producing instead CO_2 and water vapour [4]. Despite the lower luminosity of the sun [6], the mainly CO_2 atmosphere would have created an offsetting greenhouse effect [7,8], thus, ensuring temperatures sufficiently high for water to remain liquid at the surface. Partial pressures of CO_2 in the early atmosphere would have put constraints on the pH of the early ocean. Walker [7] calculates that the pCO_2 of the very early atmosphere could have been as high as 10 bars; according to Grotzinger and Kasting [9] pCO_2 could not have been below 0.03 bars otherwise the oceans would have frozen over. Higher pCO_2 results in an ocean with a low pH. Such an ocean would have been more aggressively weathering of the basaltic rocks. Furthermore, lack of O_2 in the atmosphere would have lead to high UV levels at the Earth's surface [10]. Decay of radiogenic nucleides is postulated to have created high heat flow in the early mantle [11], for which the Mg-rich komatiite lavas of the early Archaean are believed to provide some evidence [12] (although another theory postulates komatiite formation from a wetter, cooler mantle [13]).

Owing to the paucity of early Archaean rocks and their generally poor state of preservation, it is not clear to what extent the early Archaean volcanic and sedimentary supracrustal sequences were deposited upon granitoid crust. The majority of the greenstone belts appear to have been formed on (thickened?) oceanic crust [13-15], although the oldest part of the Pilbara craton seems to have been deposited on eroded continental crust [16]. The early crust was formed of small units, unlike the later platform-type continental areas which emerged later on in the history of the Earth [14,17]. A major consequence of the lack of platform areas was the lack of the large-scale carbonate deposits so characteristic of the Proterozoic era. Carbonates in the early Archaean are few and far between: primary deposits are mostly associated with evaporite sequences [9] whereas many of the so-called deep water deposits are actually the result of carbonate metasomatism [18]. Sedimentary deposits consisted of volcaniclastics, mass wasting products and chemical precipitates (especially silica, evaporites and BIFs) [14, 15, 19], deposited in a variety of environmental settings ranging from deep water turbidites, through shallow water, deltaic to alluvial settings. Strong hydrothermal activity was associated with the volcanism and gave rise to strong metasomatism as well as primary hydrothermal deposits [20,21]. On top of this scenario for the early Earth was the late heavy bombardment of the Earth and the Moon which terminated at about 3.8 b.y. One theory has this period lasting from about 4.2-3.8 b.y [22] whilst another proposed a spike in bombardment between 4.0-3.9 b.y. [23]. It hypothesised that some of the impacts could have been of such a cataclismic nature as to completely sterilise the Earth [24].

Early Life

The oldest circumstantial evidence for life (isotopic) indicates that it was well-developed and flourishing by >3.8 b.y. [25]. This means that it survived the period of heavy bombardment, UV radiation, heat, relatively acidic pHs etc. Current theories favour a hydrothermal origin of life based on 16sRNA sequencing [26-28] although there is an alternative "cold start" theory [29]. Or possibly life took refuge in vents during heavy bombardment, thus skewing the record. The oldest morphological evidence for life comes from silicified body fossils (filamentous, coccoid and rod-shaped bacteria [30-32]) as well as their associated biofilms [33,34]. All fossils found to date occur in shallow water to tidal sediments. It is possible that they occur in other environments, such as hydrothermal vents [35] or deeper water sediments such as the alteration rinds of pillow basalts. Relevant studies are underway to determine their environmental distribution.

Apart from their simplicity, one of the key characteristics of these fossils is that they are preserved by silicification (with varying degrees of organic preservation [34]). None of the fossils have been calcified. $CaCO_3$ is not a good preserver of fossils, partly because of its coarse crystal lattice relative to silica (very fine detail can be preserved with silica [36], and partly because of its susceptibility to recrystallisation and dissolution.

Early Mars

There is a general concensus that early Mars was similar to early Earth, but exactly how similar were they? The recent observation of magnetic lineations in the ancient crust of Mars [37, 38] suggests that Mars may have been tectonically active although its dynamo appears to become extinct by about 4 b.y. The dry mantle, however, indicates that there was little if any overturning of hydrated crust. Indications for water activity are strong on the older surfaces of the planet [39] but weaker on post Noachian surfaces [40]. The early CO2 atmosphere could still have been as high as 0.5-1 bar by the end of heavy bombardment [41]. Such pressures would indicate lower pH in the hydrosphere. By analogy with the Earth, the lack of continental platforms would probably preclude the existence of large carbonate deposits (carbonates therefore will not contribute to the loss of the CO2 atmosphere which was more likely due to impact erosion and sputtering [42]). The active surficial hydrosphere disappeared towards the end of the period of heavy bombardment since when most of the water appears to be stored in a subsurface crysosphere [43]. Volcanism, on the other hand, has always been present [44,45] and could melt the cryosphere. With the same indigenous and exogenous volatile input, liquid water, and sources of energy as the Earth, life could have started on Mars, becoming extinct at the surface as the hydrosphere disappeared [46]. However, life would not have had the chance to develop beyond the prokaryote stage. If it is extant, it may still be found in a dormant stage in the cryosphere.

What and Where?

Mars could still retain vestiges of the prebiotic stage of life which has been obliterated on Earth. We need to understand how that prebiotic stage can manifest itself (in terms of chemical and morphological fossils). I would therefore look for both prebiotic and simple biogenic structures (similar to bacteria and biofilms), containing organic matter or replaced by a mineral. I would especially search for silicified fossils (by comparison with the early Earth, they should be abundant if there was life on Mars). Oxidants at the surface may obliterate chemical fossil biomarkers but silicified biogenic (or prebiotic) structures could still conserve some characteristic signature [47]. Subsurface samples may contain this biochemical fossils. With impact gardening, potential fossils in older formations could be both strewn around the surface as well as pulverised or shock metamorphosed. We need to be able to identify shocked fossils (organic and minerally replaced). There are manifestations of early life on Earth in all ancient, water-associated rocks that have not been heavily metamorphosed, *i.e.* it appears to have been widely distributed from the earliest Archaean. Could the same be true for Mars? In that case we could find potential fossils from shallow water, hydrothermal deposits, evaporite deposits, on pillow basalt surfaces, in cracks in igneous and metamorphic rocks in almost any location, spread by impact. The large deposits of coarse grained hematite [48] prompted excited comparisons with terrestrial BIFs (which have some biogenic component) but they may have been compromised by metamorphism [49] and, therefore, unsuitable as fossiliferous locations.

[1] McKay, D.S. et al. (1996) Science, 271, 924. [2] Delano, J.W. (1994) LPSC XXIV, p.395. [3] Delano, J.W. (2000) Ist Astrobiology Science Conf. April 2000, NASA-Ames, p.15.[4] Chyba, C.F. and Sagan, C. (1992) Nature, 355, 125. [5] Bowring, S.A. and Housh, T. (1995) Science, 269, 153. [6] Kuhn, W.R. et al. (1989) J. Geophys. Res., 94, 11,129. [7] Walker, J.C.G. (1985) Origins of Life, 16, 117. [8] Kasting, J.F. (1993) Science, 259, 920. [9] Grotzinger, J.P. and Kasting, J.F. (1993) J. Geology, 101, 235. [10] Sagan, C. (1973) J. Theor. Biology, 39, 195. [11] Pollack, N.H. (1997) *In* de Wit, M.J. and Ashwal, L.D. (Eds) Greenstone Belts, Oxford Univ. Press, p. 223. [12] Vlaar, N.J., et al. (1994) Earth Planet Sci. Lett. , 121,1. [13] de Wit, M.J. (1998) Precambrian Res., 91, 181. [14] Lowe, D.R. (1980) Ann. Rev. Earth Planet. Sci., 8, 145. [15] Eriksson, K.A. et al. (1994) Earth-Science Rev., 37, 1. [16] Buick, R. (1995), Nature, 375, 574. [17] Grotzinger, J.P. (1989) *In* Controls on Carbonate Platform and Basin Devolopment, SEPM Spec. Pub. 44. [18] Rose, N.M. et al. (1996) Am J. Sci., 296, 1004. [19] Fedo, C.M. (2000) Precambrian Res., 101, 69. [20] de Wit, M.J. et al. (1982] Econom. Geol., 77, 1783[21] Chown, E.H. et al. (2000) Precambrian Res., 101, 263. [22] Hartmann, W.K. (1980) *in* J.J. Papike and R.B. Merrill (Eds) Proc. Conf. Lunar Highlands Crust, p. 155. [23] Hartmann W.K. et al. (2000) Origins of the Earth and Moon, in press. [24] Maher, K.A. and Stevenson, D.J. (1988) Nature, 331, 612. [25] Mojzsis, S.J. et al. (1996) Nature, 384, 55. [26] Woese, C.R. (1987) Microbiol. Rev., 51, 221. [27] Baross, J.A. and Hoffman, S.E. (1985) Origins of Life, 15, 327. [28] Russell, M.J. and Hall, A.J. (1997) J. Geol. Soc. Lond., 154, 377. [29] Galtier, N. et al. (1999) Science, 283, 220. [30] Walsh, M.M. (1992) Precambrian Res., 54, 271. [31] Schopf, J.W., (1993) Science, 260, 640. [32] Westall, F. et al. (2000) Precambrian res., in press. [33] Walter, M.R. (1983) *In* Schopf, J.W. Earth's Earliest Biosphere, p.187. [34] Westall, F. et al. (2000) J. Geophys. Res., in press. [35] De Ronde, C.E.J. and Ebbesen, T.W. (1996) Geology, 24, 791. [37]Westall, F. et al. (1995) Palaeontology, 38, 495. [37] Acuña, M.H. et al. (1999) Science, 284, 790. [38] Connery, J.E.P. et al. (1999) Science, 284, 794. [39] Carr, M.H. (1996) Water on Mars. Oxford Univ. Press. [40] Malin, M.C. and Carr, M.H. (1999) Nature, 397, 589. [41] Carr, M.H. (1999) J. Geophys. Res., 104, 21,897. [42] Brain, D.A. and Jakosky, B.M. (1998) J. Geophys. Res., 193, 22,689. [43] Fanale, F.P. et al. (1986) Icarus, 67, 1. [44] McEwen, A.S. (1999) Nature, 397, 584. [45] Hartmann, W.K. et al. (1999) 397, 586. [46] Friedmann, E.I. and Koriem, A.M. (1989) Adv. Space Res. 9(6), 167. [47] Westall, F. et al. (2000) LPSC XXX, 1707. [48] Christensen, P.R. et al. (2000) J. Geophys. Res., 105, 9623. [49] Lane, M.D. et al., (2000) LPSC XXX, 1140.

RAPID ELEMENTAL ANALYSIS AT STAND-OFF DISTANCES USING THE LIBS CONCEPT FROM THE MARS INSTRUMENT DEVELOPMENT PROGRAM. R. C. Wiens, D. A. Cremers, M. Ferris, and J. D. Blacic, Los Alamos National Laboratory (MS D-466, Los Alamos, NM, 87545, rwiens@lanl.gov).

Introduction: The elemental composition of rocks and soils is one of the most fundamental types of information needed to understand geologic contexts and to search for likely locations of biological activity. Nearly all methods for determining elemental composition involve in-situ analysis, requiring time-consuming maneuvering of a rover to acquire the desired sample. By contrast, analyses at stand-off distances allow nearly a ten-fold increase in the number of samples obtainable over in-situ techniques [1]. Additionally, methods such as APXS have difficulty distinguishing between the pristine sample and rock coatings of either dust or weathering products [2].

Under the auspices of the Mars Instrument Development Program, we have built and are testing a prototype LIBS (Laser-Induced Breakdown Spectroscopy) instrument which can rapidly determine elemental compositions at a distance. Additionally, by depth profiling µm to mm into the sample, LIBS can distinguish between dust or weathering products and the pristine sample. Here we summarize the LIBS concept, describe the initial performance of our prototype, including work at the combined rover tests in Nevada, and summarize potential LIBS contributions to the Mars exploration program.

The LIBS Concept: In the LIBS method [3], powerful laser pulses are focused on the target sample to form a laser spark or plasma. Material within the spark is the result of vaporization/atomization of a small amount of target material. The spark light contains the emission spectra of the elements within the plasma. Collection of the plasma light, followed by spectral dispersion and detection, permit identification of the elements via their unique spectral signatures. When calibrated, concentrations can be determined. Advantages of the method compared to more conventional elemental analysis methods include: (1) rapid analysis (one measurement/pulse); (2) simultaneous multi-element detection; (3) ability to detect all elements (high and low z); (4) ability to clean dust or weathering layers off of sample surfaces; and (5) stand-off analysis capability [4]. Stand-off analysis is possible because the laser pulses can be focused at a distance to generate the laser sparks on a solid. The distance that can be achieved depends on characteristics of the laser and the optics used to focus the pulses on the target.

Recent LIBS Results: We have recently shown [5,6] using a laboratory instrument that a) semi-quantitative results (e.g., 10-20% accuracy) can be obtained for nearly all elements at stand-off distances of up to 20 m. using a compact laser and a 4" objective lens and detector, b) detection limits for nearly all elements at these distances are in the range of 10 to several hundred ppm, c) LIBS works well at all atmospheric pressures from 1 bar to vacuum, with a maximum efficiency between 10 and 100 Torr, and d) the target mass ablated per laser pulse increases with decreasing atmospheric pressure.

The capability to remove surface material from a sample is important, as all Mars rock observations to date appear to be contaminated with dust [2]. In one recent test, layers of sea sand 1, 2, and 3 mm thick overlying a rock sample were removed in 4, 14, and 28 laser pulses, respectively, under Martian conditions (5 Torr CO_2 atmosphere) [5]. Typical excavation rates for the ~1 mm dia laser-produced craters in basalt are much lower, at ~1 µm/shot, but still sufficient to remove weathering layers with repeated pulses.

Prototype Design and Testing: A relatively simple prototype instrument was produced over the last year. As shown in Fig 1, it consists of two sections: 1) the sensor head, including the laser, variable focus beam expander with a 2" diameter objective lens, beam splitter, and a fiber optic couple for receiving the return signal. 2) The body-mounted portion consists of the spectrograph and detector, and the laser controller. Commercial off-the-shelf (COTS) components were used throughout, so weight, instrument volume, power consumption, and some of the optical parameters were not optimized. The prototype was built to fit the K9 rover testbed fielded by NASA Ames. Its working range is 2-6 m, the near distance limited primarily by the height of the rover masthead. The working spectral range is from 240 to ~800 nm, with a resolution of ~2 nm. The YAG laser output is ~100 mJ in ~10 ns pulses, with a repetition rate of 0.1 Hz, limited by thermal considerations.

The prototype was integrated with the rover and tested during the combined rover tests at Lunar Lake, NV in May, 2000. Due to the fire at Los Alamos, which resulted in lab closure and evacuation of the entire county, we were not able to support the testing as planned, and obtained only limited data at the test site. A portion of a spectrum obtained using a single laser shot during the field test is shown in Fig. 2. Joint Wash. U./LANL comparison of reflectance spectroscopy, XRF, and LIBS results are planned as follow-up work on a dozen rocks taken from the site.

Calibration data were taken at several stand-off distances prior to the rover exercises. Samples con-

RAPID ELEMENTAL ANALYSES AT STAND-OFF DISTANCES VIA LIBS: R. C. Wiens *et al.*

sisted of standard rock powders. Fig. 3 compares a portion of the spectrum containing Mg and Si peaks for rock powders of pyroxenitic, basaltic, and granitic compositions. Spectra from 10 laser shots were averaged, with a stand-off distance of two meters.

Envisioned Applications: The results show that semi-quantitative elemental compositions are rapidly obtainable at stand-off distances using an instrument of this format. "Quick-look" compositions of rocks and soils some distance from the rover provide a rapid way to determine a) which direction a rover should travel and b) where to use more time-consuming in-situ analysis techniques.

Rapid, stand-off analysis is only one possible application of LIBS, which could be done either using a compact rover-mounted instrument of $\leq$1.5 kg with capabilities similar to the prototype, or using a slightly more robust lander-mounted instrument capable of 20+ m stand-off distances, though this is perhaps more applicable to, e.g., a Europa lander. The detector portion of such an instrument could double for Raman spectroscopy analyses [7] to yield mineralogical information at stand-off distances [8] as well. If more quantitative elemental analyses are desired from LIBS, such as to aid in radiometric dating, in-situ analyses using a fiber optic cable mounted adjacent to the sample can be done.

References: [1] Arvidson R.E. et al. (1998) A mission model for the 2001 Mars Rover/Athena payload, presented at the Mars Surveyor 2001 Landing Site Workshop Program, NASA Ames. [2] McSween H.Y. Jr., et al. (1999) *JGR 104*, 8679-8715. [3] Cremers D.A. and Radziemski L.J. (1986) In *Laser Spectroscopy and Its Applications* (L.J. Radziemski, et al., eds.), Chapter 5, Marcel Dekker, New York. [4]Cremers D.A. (1987) *Appl. Spectrosc. 41*, 1042. [5] Knight A.K. et al. (2000) *Appl. Spectrosc. 54*, 331. [6] Knight A.K. et al. (1999) *Lunar Planet. Sci.XXX*, 1018-1019. [7] Wiens R.C. et al., (2000) *Lunar Planet. Sci. XXXI*, 1468-1469. [8] Lucey P.G. et al. (1998) *Lunar Planet. Sci. XXIX*, 1354-1355.

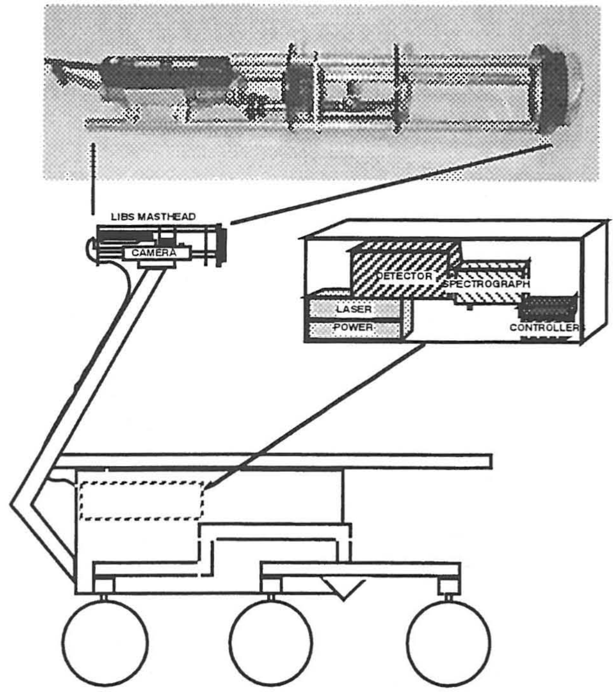


Fig. 1. Schematic view of the LIBS prototype components as mounted in the K9 rover testbed. The photo shows the sensor head with the cover removed. The prototype used only COTS parts, so weight and volume have not yet been optimized.

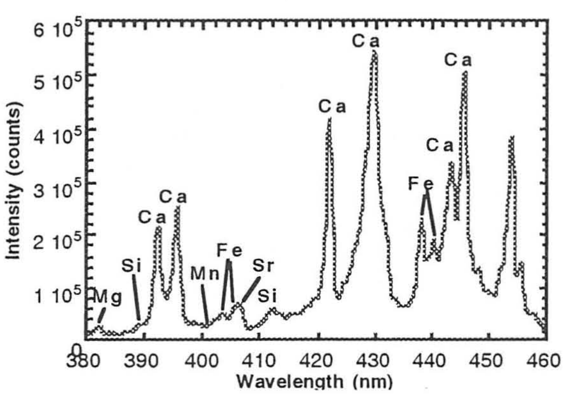


Fig. 2. Spectrum of a basalt rock recorded by the LIBS prototype on the K9 rover during field tests. This spectrum was obtained using a single laser pulse.

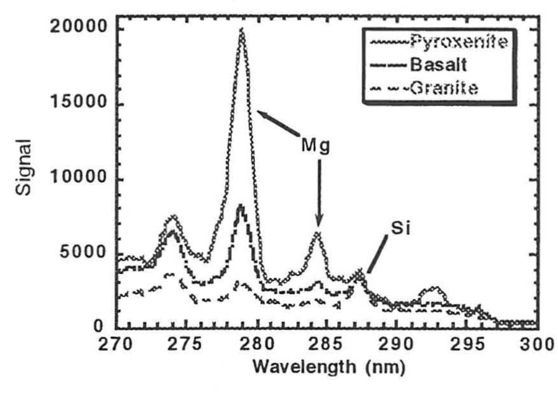


Fig 3. A portion of the spectrum showing two Mg peaks and a Si peak. The three rock types are very easily distinguished from the Mg/Si ratio. Ten-spectra averages were taken on standard rock powders at 2 m. The MgO abundance ranges from 25% to 4% to 0.04%.

A MINIATURE MARS ASCENT VEHICLE. B. H. Wilcox[1], Jet Propulsion Laboratory, California Institute of Technology, M/S 107-102, 4800 Oak Grove Dr. Pasadena, CA 91109, [1]Brian.H.Wilcox@jpl.nasa.gov.

Abstract: Launch of payloads from the surface of the Mars is a central element in any Sample Return program, and represents one of the most important objectives of NASA planetary science and HEDS programs. Analysis of these samples in the sophisticated laboratories of Earth will give vastly more scientific as well as HEDS-relevant engineering and space-medicine knowledge of those bodies than can be performed from any feasible near-term miniaturized instruments. What is proposed here is a launch system with no moving parts of any kind: no gyroscope, no accelerometers, no control surfaces, and no thrust vector control. This concept is an enhancement and improvement based on the formerly-classified PILOT microsatellite launching system developed by the U.S. Navy at the China Lake Naval Ordinance Test Station (NOTS) in 1958. Developed as a crash program in response to the Soviet launch of Sputnik 1, the PILOT all-solid rocket launcher was about an order-of-magnitude lighter than conventional orbital launch vehicles developed before or since, and had no moving parts or control system. With a launch mass of under 1000 kg, it was dropped from the wing of a fighter plane climbing at about 70 degrees from horizontal, and used a first stage to lob it above the atmosphere. It had fins which were slightly canted to make the rocket roll slowly about its axis, giving it a gyroscopic moment. The atmospheric drag acted on the fins to keep the vehicle axis roughly tangent to the trajectory. About 80 Km up, the trajectory became approximately horizontal. An optical detector sensed the horizon, triggering the second stage when the vehicle was approximately horizontal. A third stage was ignited by the burnout of the second stage. These latter two stages together achieved almost the entire Earth orbital velocity of 8500 m/s. A fifth stage was mounted backwards to the other stages inside the payload, initiated by a 53 minute timer. The gyroscopic moment of this oblate payload kept the payload stabilized inertially in space for enough time to go half way around the Earth. The last stage, backwards to the flight direction at launch, kept its inertial direction and was thus pointed forward along the orbital direction on the other side of the orbit. When the timer fired the last stage it gave the "apogee kick" needed to put the satellite into a long-life orbit. This approach was declassified in 1984, and it became known to this author since the originator and project manager of PILOT happened to be this author's father.

The difficulty with this approach is that, in its original form, there is a very limited ability to prespecify the orbital parameters which result from this unguided launcher. Following this author's proposal to use the original PILOT concept for Mars Sample Return in June '98, the concept of using a spin-stabilized upper stage to avoid the need to accelerate a guidance and control system to orbital velocity was adopted as the baseline for the Mars Sample Return mission studies at JPL, reducing the development cost from an estimated $170M to $50M and the mass from 400 kg to about 100 kg. However, there substantially greater benefits yet to be reaped, enabling not only a greatly reduced cost for Mars Sample Return, but also enabling Venus Sample Return, Mars micromission/polar sample returns, Mercury sample return, and low cost lunar polar sample return.

The basic PILOT system is extended and significantly enhanced by three new ideas for this proposed activity: 1) that the aerodynamic tipover of the vehicle at the top of the atmosphere can be modeled as a nonuniform gyroscopic precession and can be accurately predicted and controlled by appropriate selection of the initial conditions of vehicle configuration and launch to give a relatively precise orbit injection, 2) that the final orbit injection stage can be configured around the payload so as to make the total system both oblate (and therefore spin stable for its half-orbit coast up to apoapsis) and to protect the payload from aerodynamic forces (e.g. no separate payload shroud is required), and 3) that the final stage assembly can have a beltline of small, single shot thrusters around its equator to allow correction of whatever orbit insertion errors may occur in the flight of this unguided rocket by use of tracking and remote control commands from the rendezvous vehicle. None of these concepts were incorporated in the PILOT system or any subsequent orbital launch system. A provisional patent application on these innovations has been filed to protect the government interest in these key features which will enable the PILOT concept to be effectively used both for low cost Earth orbital launch of small or large payloads, and some of them enable extremely small and low-cost sample return missions from any of the terrestrial planetary bodies of the solar system.

The key to building a miniature Mars Ascent Vehicle (MiniMAV) which can be put into a precise orbit for rendezvous is to create an integrated orbit injection canister with the following properties: it has an oblate, spin stable mass distribution, it has the return sample along the geometric spin axis, it has a circularization thruster also mounted on the spin axis, and it has a beltline of trim thrusters and a remote control receiver to fire them at specified times to modify the orbit as needed for rendezvous. Figure 1 shows a configuration consistent with these requirements.

The oblate mass distribution is required so that the canister remains spin stable during the half-orbit from the time of the orbit injection burn to the time of the circularization burn at apoapsis, as needed to ensure that the circularization thruster is pointed in the correct direction for that burn. By making the mass distribution oblate, a passive nutation damper can be used to remove the excitation introduced by the inevitable slight offpointing of injection burn. Perhaps the best way to ensure that the mass distribution is oblate is to incorporate the final injection stage into the canister. This last stage will be injected to orbital velocity anyway, and it's extra mass allows greater flexibility in the configuration of the system elements to ensure the needed overall mass properties. Accelerating this spent mass with the circularization burn is less of a penalty than trying to separate from it.

Placement of the planetary sample on the spin axis is needed to ensure that the mass properties of the canister as a whole are very well controlled, as needed by the uncontrolled flight dynamics of the vehicle. A preliminary study effort has been conducted to evaluate the feasibility of insulating this sample from the thermal pulse of both the injection and circularization rockets and the mass penalty seems acceptable.

The circularization thruster must be on the spin axis of the canister so that there is minimal thrust offset in performing the circularization burn. Placing the circularization thruster in front of the sample and making it the access point for sample insertion in t he center of the injection stage, as shown in Figure 1, has several advantages. It allows the injection stage to have minimum surface to volume ratio and to be a single nozzle system, so that there are no issues of burn or thrust synchronization or matching which could be catastrophic. Furthermore, it allows the circularization burn to heat the bond line where the sample is inserted to incendiary temperatures, melting a bead of brazing compound around the seal and sterilizing the exterior of the bond line for purposes of planetary protection. The remainder of the spherical surface of the canister can be protected with a frangible bioseal which is blown off by the burn of the various thrusters.

Trim thrusters are arranged around the beltline of the canister. These assist in creating the oblate mass distribution and are key to allowing the canister to perform the bulk of the delta-V maneuvers which are needed to rendezvous with the Earth Return Vehicle (ERV). These thrusters would be fired by remote control from the ERV. Since the ERV must be able to acquire and track the canister, it necessarily has assets such as a beacon receiver and optical tracking camera which can locate the canister. If the canister is painted half white and half black, it will "blink" in the sunlight as it spins. The ERV can then determine the phase of rotation from this blinking optical signature, and use it to time remote control commands for firing of the trim thrusters. Normally these thrusters would be fired at the point of the plane crossing of the two vehicles, and so the vehicles can be very close together at the time that the remote control commands are sent.

Once the canister is in the correct orbit for rendezvous, it consists of a spherical mass of spent rocket motor casings and refractory structure which is all capable of exposure to extremely high temperatures. The fill material between the rocket motors could be composed of material similar to Space Shuttle thermal protective tile. With the sample embedded deep in it's center, it is possible that this canister can be used directly as the Earth entry capsule. The estimated terminal velocity for this assembly in Earth's atmosphere is about 15 m/s. It seems plausible that the canister could be designed to survive impact at this velocity, which would allow the whole rendezvous sample handling chain to be eliminated, greatly reducing the mass and cost of the mission.

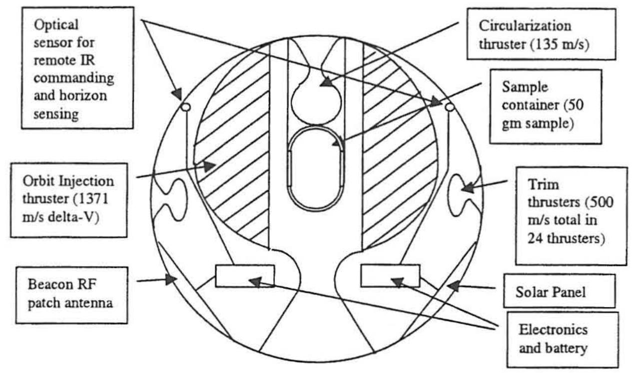


Figure 1: Schematic of Injection Stage Assembly.

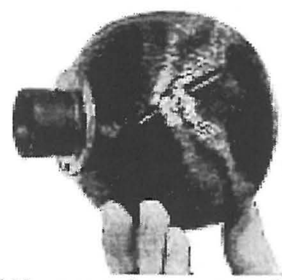


Figure 2: Thiokol Nanosat rocket motor developed for GSFC

NANOROVERS AND SUBSURFACE EXPLORERS FOR MARS. B. H. Wilcox, Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 107-102, 4800 Oak Grove Drive, Pasadena CA 91109, USA (Brian.H.Wilcox@jpl.nasa.gov).

Abstract: Recent advances in microtechnology and mobile robotics have made it feasible to create extremely small automated or remote-controlled vehicles which open new application frontiers. One of these possible applications is the use of nanorovers (robotic vehicles with a mass of order 1 Kg or less) in planetary exploration. NASA and Japan's Institute of Space and Astronautical Science (ISAS) are cooperating on the first mission to collect samples from the surface of an asteroid and return them to Earth for in-depth study. The ISAS MUSES-C mission will be launched on a Japanese launch vehicle in July 2002 from Japan toward a redezvous with the asteroid 1989ML in September 2003. A NASA-provided nanorover will conduct in-situ measurements on the surface. With a mass of about 1kg, the rover experiment will be a direct descendant of the technology used to build the Sojourner rover. The rover will carry three science instruments: a visible imaging camera, a near-infrared point spectrometer and an alpha X ray spectrometer. The solar-powered rover will move around the surface of 1989ML collecting imagery data, which are complimentary to the spacecraft investigation. The imaging system will be capable of making surface texture, composition, and morphology measurements at resolutions better than 1 mm. The rover will transmit this data to the spacecraft for relay back to Earth. Due to the microgravity environment on 1989ML, the rover has been designed to right itself in case it flips over. Solar panels on four sides of the rover will ensure that enough power will always be available to the rover to activate the motors needed to turn over. Posable struts will allow the rover to position its chassis such that the camera can be pointed straight down at the surface or straight up at the sky.

The rover has been designed with the capability to right itself if it flips onto its back. Since the four posable struts are independent, the rover can be commanded to point itself in any orientation. A pointable mirror and actuated focus mechanism allow the rover to take panoramic images as well as microscopic ones.

The primary rover science objectives are to carry out scientific measurements with its entire instrument suite and to transmit the data before asteroid "night," at which time, the rover will shut down until sunrise. There is little non-volatile storage on the rover. Most data not transmitted to the orbiter at the end of the daily investigation schedule will be lost. Daily investigations include visual imaging of the terrain and targets of interest, point spectra in the infrared, AXS spectra, and soil mechanics investigations using the rover as an instrument.

The rover consists of a rectangular body, which is 14 14×6 cm in dimension with four wheels on four posable struts for mobility. The wheels are 6.5 cm in diameter, mounted on struts, which extend in pairs from hubs emerging from the geometric center of two opposing 14×6 cm faces of the body. Each strut is 7 cm long from the center of their pivot to the center of the wheel axis. Four of six faces of the rover body have solar cells for power generation. The top face also has the antenna element needed to transmit the radio signal. The rover can communicate as long as it is powered, with a line-of sight range of about 20 km.

The rover has optical detectors on all six orthogonal exterior faces of the rover. Using these detectors, the rover will be able to determine the direction to the sun. Vertical sensing is not possible due to the unavailability of accelerometers which can measure the microgravity fields of asteroids and yet fit within the mass constraints of the rover. The rover has a laser range finder, which enables it to determine the range to nearby objects. This serves a similar function to the mast-mounted stereo lander cameras used in conjunction with the Sojourner rover to localize the 3-D positions of science and engineering targets, hazards, and other objects.

The rover carries three science instruments, the visual camera, the near infrared spectrometer and the alpha X ray spectrometer. There is view window on the front face for the camera and IR spectrometer. The AXS sensor will open out to the rear of the rover and be placed in contact with rock or regolith by appropriate body/strut motion.

The entire rover system is being qualified for the temperature range of -180°C to +110°C, which is derived from the worst case situations during the mission. The mechanical environment for the rover is dominated by the vibration environment imposed by the ISAS MV launch vehicle. The MV is an "all solid" design and, as such, provides a relatively "rough ride". To be conservative, the mechanical elements of the rover are being designed to 100Gs and the OMRE to 125Gs. The entire rover is also being designed to be compatible with a radiation dose of about 25krad, although many components will tolerate much higher levels.

Application of the nanorover to Mars is straightforward: indeed the research program under which the basic technology of the nanorover was created had Mars as the original target. Although the solar power density is less on Mars than on the MUSES-C mission target, the lower operating temperature of the solar panel should cause the amount of power available on Mars to be comparable or greater than that on the asteroid. The only hardware modification needed for Mars is the inclusion of brakes on the mobility actuators so that the vehicle can "park" without rolling or changing pose. Fortunately, accomodations for these brakes are already included in the nanorover design.

Another small robotic vehicle, the Subsurface Explorer (SSX), is being developed at the Jet Propulsion Laboratory which is suitable for exploration of the deep underground environments on Mars. The device is a self-contained piledriver which uses a novel "spinning hammer" technology to convert a small continuous power feed from the surface over a two-wire tether into a large rotational energy of a spinning mass. The rotational energy is converted to translational energy by a novel mechanism described here. The hammer blows propagate as shock waves through a nosepiece, pulverizing the medium ahead of the SSX. A small portion of the pulverized medium is returned to the surface through a hole liner extending behind the SSX. This tube is "cast in place" from two chemical feedstocks which come down from the surface through passages in the hole liner and which are reacted together to produce new material with which to produce the hole liner. The lined hole does not need to be the full diameter of the SSX: approximately 100 kilograms of liner material can create a tunnel liner with a 3 mm inside diameter and a 6 mm outside diameter with at total length of 4 km. Thus it is expected that core samples representing an overlapping set of 3-mm diameter cores extending the entire length of the SSX traverse could be returned to the surface. A pneumatic prototype has been built which penetrated easily to the bottom of an 8 meter vertical test facility. An electric prototype is now under construction. It is expected that the SSX will be able to penetrate through sand or mixed regolith, ice, permafrost, or solid rock, such as basalt. It is expected that an SSX approximately 1 meter long, 3-4 cm in diameter, and with a power budget of approximately 200 Watts will be able to explore up to ~5 kilometers deep at the rate of about 10 meters per day. A preliminary subsurface exploration mission could be conducted as early as 2005, with penetration of hundreds of meters to characterize the local gradients of temperature and redox potential and perhaps locate the top of the cryosphere, for example.

THE IMPORTANCE OF BRINGING SAMPLES OF MARS TO EARTH. J. A. Wood[1] and W. V. Boynton[2], [1]Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge MA 02138, jwood@cfa.harvard.edu, [2]Lunar & Planetary Laboratory, University of Arizona, Tucson AZ 85721, wboynton@lpl.arizona.edu

Introduction: A basic goal of the Mars Surveyor Program, begun in 1996, was the delivery to Earth of carefully chosen samples of Mars surface material. Interest generated by the proposition that Mars meteorite ALH84001 displays evidence of extraterrestrial life, also put forward in 1996, intensified interest in the Mars Surveyor Program in general and sample return in particular. As we all know, however, the character of the projected Surveyor program has changed dramatically with the failures of the Mars Climate Orbiter and Mars Polar Lander missions and the realization that ambitious goals must be scaled back. Most notably, the concept of sample return from Mars has all but disappeared from the dialogue about Mars exploration in the next decade. Remote analysis of surface materials by instruments on landed rovers is offered as the next-best option.

This paper argues that remote analysis is not even in the same league as the study of samples in terrestrial laboratories, and that every effort should be made to fulfill the goal of sample return at the earliest opportunity. Remote analysis is inferior to laboratory study in two fundamental ways.

1. Scale: To date, remote analysis of planetary materials has been limited to measurements of some of their bulk properties. This is a very crude tool to have to rely on. For the better part of 200 years Earth rocks have been studied at the microscopic level, and the same is true of meteorites and (when they became available) lunar samples. Most of what we know about terrestrial and extraterrestrial rocky materials has come from imaging at the microscopic level, and in recent decades from the use of microbeam instruments to reveal microchemical structures and isotopic patterns in these materials. The machinery required to prepare materials for these studies and perform the analyses is complex and massive; it does not lend itself to miniaturization for spacecraft payloads. Undoubtedly a time will come when simple forms of microanalysis become possible on remote planetary surfaces, but these portable techniques will always lag far behind what is possible in terrestrial laboratories.

The microscopic study of sections of rock, or soil particles, lays open a wealth of detailed information that cannot be obtained by bulk analysis. Examples are shown in Figs. 1 and 2, which are thin sections of terrestrial sedimentary rocks, illuminated by transmitted light. Our choice of sedimentary rocks is in the spirit of the recommendation of [1] that such materials should have a high priority in sampling Mars, because of the importance of the search for past or present life there, and evidence they would contain of the climate and volatile history of Mars.

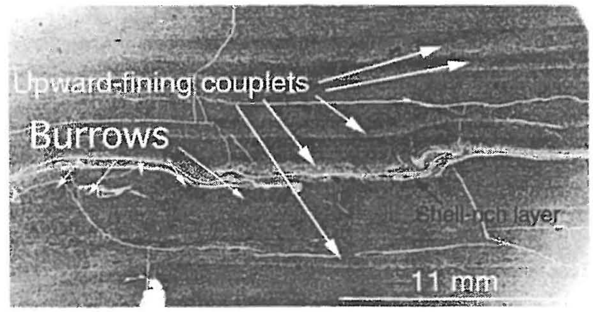


Figure 1. Thin section of the Kildonnan Member mudstone, Mid-Jurassic, Scotland. Courtesy of Joe Macquaker, Manchester University, UK.

Figure 1 shows a mudstone consisting mostly of <50 μm particles of clay and other minerals. Each "upward-fining couplet" in the section records a discrete paleoclimatic episode on Earth— a storm— in which a batch of muddy water entered the volume where this rock originated and the mud settled, coarser grains while the stream flow was fast and finer grains as it slowed. The individual grains contain information about source rocks in the drainage area where they originated, far upstream. Microbeam analysis techniques have advanced to the point where a very large amount can be learned, *in terrestrial laboratories*, from a single 10-μm mineral grain (Fig. 3).

Note that one episode during the time when this rock was being assembled deposited a thin layer of fossil shell fragments, and that during quiescent periods bottom-dwelling organisms burrowed into the sediment surface. The relevance of these microscopic features to stream-laid martian rocks is, of course, unknown.

Figure 2 is a section of a terrestrial *wacke*, or poorly-sorted sandstone, a coarser class of sediment that forms close to the source of its components. Because little stream transport is involved, size-sorting has been minimal. The presence of relatively large (mm-scale) particles in such rocks is important because samples this large can be polymminerallic, and ion microprobe study of the isotopic structures in their constituent minerals can yield radiometric ages of the source rocks. (The same is true of rock particles in soil samples.)

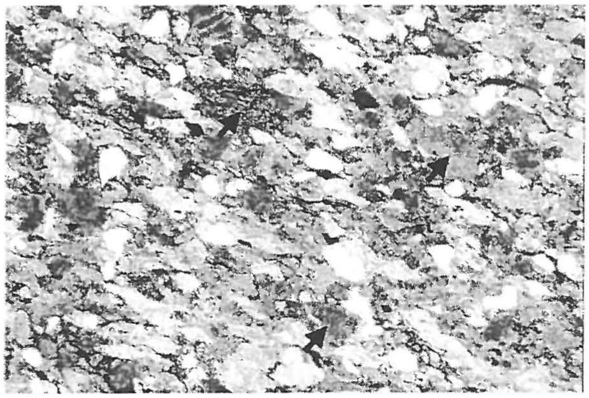


Figure 2. Thin section of graywacke from the Carboniferous Anaiwan Terrane, Australia. Width of field, 5 mm. Coarse mineral clasts are plagioclase, orthoclase, quartz, and hornblende. Arrows point to dacitic and andesitic lithic clasts. Courtesy of Bill Landenberger, Univ. Newcastle, Australia.

2. Adaptability: When analytical instruments are miniaturized for flight payloads, it is at the expense of versatility and repeatability. The optimal type of measurement, and the range of parameter space to be explored, must be prejudged. If an inappropriate measurement is chosen (as in the case of the Viking life detection experiments), the error cannot be corrected. If what is learned points to the importance of other wavelength ranges, or greater sensitivity, or some other change in instrumentation, typically this must wait for a later mission.

Science, by its very nature, is exploratory and iterative. Each result obtained poses another question and points to a new type of measurement. The learning path consists of many steps of this sort. In a terrestrial laboratory such a path can be followed for years through its many iterations, especially now that many measurements can be made with so little consumption of material (Fig. 3). This is not possible with remote spacecraft measurements. Even in cases where there might be enough flexibility in the instrumentation to accommodate additional iterations, the duration of experimentation is limited by the supply of expendables and the lifetime of spacecraft components.

Concluding remarks: It is instructive to compare two contributions that spacecraft made to our knowledge of the moon. Surveyor 5, in 1966, made bulk analyses of the surface of Mare Tranquillitatis. It was a completely successful mission, and the analyses confirmed the basaltic character of lunar maria. But we know vastly more than this about the moon now, and our rich knowledge of that body has come almost entirely from the samples that were brought to terrestrial laboratories by the Apollo astronauts. Without laboratory studies we could not know the ages of rocks and the chronology of events on the moon, or the petrologic nature of terra rocks and the processes that created them, or the rare-earth patterns in lunar basalts that informed us of the moon's internal evolution, or many other important properties of the moon.

Our understanding of Mars will be similarly retarded until we can study samples of that planet in terrestrial laboratories.

[1] Mars Program Architecture: Recommendations of the NASA Astrobiology Institute, 1/10/00. [2] Zolensky, M. E. et al. (2000) *MAPS* **35**, 9-29.

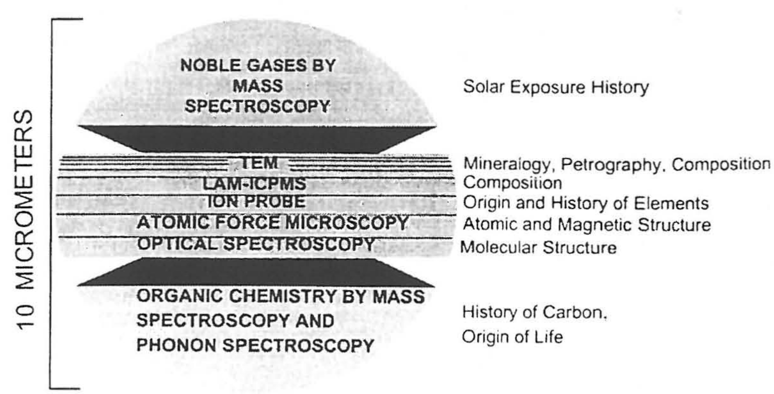


Figure 3. Hypothetical study of a single 10-μm sample of extraterrestrial material which has been sliced by a microtome and studied by a consortium of terrestrial laboratories. Figure from (2).

IMMERSIVE ENVIRONMENT TECHNOLOGIES FOR MARS EXPLORATION J. Wright and F. Hartman, Jet Propulsion Lab, john.r.wright@jpl.nasa.gov, frank.hartman@jpl.nasa.gov

Introduction: JPL's charter includes the unmanned exploration of the Solar System. One of the tools for exploring other planets is the rover as exemplified by Sojourner on the Mars Pathfinder mission. The lightspeed turnaround time between Earth and the outer planets precludes the use of teleoperated rovers so autonomous operations are built in to the current and upcoming generation devices. As the level of autonomy increases, the mode of operations shifts from low-level specification of activities to a higher-level specification of goals. To support this higher-level activity, it is necessary to provide the operator with an effective understanding of the in-situ environment and also the tools needed to specify the higher-level goals. Immersive environments provide the needed sense of presence to achieve this goal.

Use of immersive environments at JPL has two main thrusts that will be discussed in this talk. One is the generation of 3D models of the in-situ environment, in particular the merging of models from different sensors, different modes (orbital, descent, and lander), and even different missions. The other is the use of various tools to visualize the environment within which the rover will be operating to maximize the understanding by the operator. A suite of tools is under development which provide an integrated view into the environment while providing a variety of modes of visualization. This allows the operator to smoothly switch from one mode to another depending on the information and presentation desired.

Terrain Modelling: The creation of 3D models of the in-situ environment begins with imagery collected by orbiting instruments which utilize stereo image processing to generate elevation maps of the terrain. Viking data has produced such elevation maps for the vast majority of Mars that are georeferenced and registered with imagery. This provides a baseline model for the 3D representation of a given operational area. Descent imagery captured by a lander is the next input and this is processed by unique methods developed at JPL to generate elevation and landmark maps of the landing area. The descent images provide lower resolution data over a large area and higher resolution data in the immediate area of the lander. The elevation maps produced from the descent imagery are then registered with the baseline dataset to create a multiresolution, georeferenced image and elevation map set.

The final piece of data is captured by the lander/rover. The stereo imagers on the lander capture the immediate surroundings at very high resolution. However, it is difficult to utilize standard image processing methods to attempt to register the lander images to the baseline model. This is due to the extreme difference in position and pespective that a lander on the surface has relative to an orbiter or other airborne instrument. The lander can image areas under overhanging boulders or other structures that are invisible in the previous datasets. To circumvent this problem, the registration process takes place in 3D utilizing the geometry of the baseline dataset to register with the geometry of the surroundings generated by stereo processing of the lander imagery. This process is well supported by the use of voxels and octrees which provide inherent multiresolution dataset support with relatively low storage requirements.

The generation of 3D models for the lander site is a process described by Ivanov, et al [1]. The process uses image correlation processes to register all the images captured by the lander cameras into a panoramic mosaic. This provides for correction of camera pointing errors. Registering the resulting 3D models to the baseline geometry provides an additional correction computation to make further improvements in pointing data and to register the models to the baseline geocoordinates. For a rover, this process can be iterated as the vehicle travels to new locations and captures stereo imagery of the surroundings. Each patch can be registered to the baseline model and the entire set of data maintained in a cohesive fashion.

Immersive Planning Tools: During Pathfinder, the terrain models built from the IMP imagery extended a few meters out from the lander. If the operators wanted to traverse to a location outside this region, there was no model and no imagery to assist them in planning the sortie. With the multiresolution datasets described above, there will be models with varying resolution extending across the entire planetary surface, or at least multiple kilometers. This will allow the operators to plan traverses to previously unexplored areas with more assurance of traversability and reduced mission risk.

As rovers gain autonomy, the sortie planning process shifts from a low level specification of commands to a higher level specification of goals. These higher level specifications will include such things as traverse to a waypoint and activate instrument at this location. The role of the operators will include more analysis of the in-situ conditions and rover state and less low level control of behavior. The Rover Control Workstation (RCW) under development provides a variety of tools, in an integrated environment, to provide the operator with the greatest understanding of the in-situ environment and rover state possible. Multiple visualization modalities, combined with a robust message passing environment, provide common views into the in-situ environment and planned activities. In addition, collaborative sortie planning operations are supported.

The RCW deployed for the Pathfinder mission was based on two basic visualization tools, the Stereo View and the Flying Camera View as described by Cooper [3]. These two basic modalities are continued in the updated version and combined with a Map View tool to provide the most important visualization functions of the in-situ environment. The Stereo View mode provides the most basic, raw look at the image data returned from the stereo imagers. The imagery is displayed using a stereo monitor with the individual stereo pairs arranged in position relative to the camera pointing when the images were captured. Use of stereo glasses provides the operator with a view of the data in its least processed form. Depth and other stereo cues allow the operator to get a fundamental feel for the environment. The minimal level of processing ensures that no artifacts have been added to the data and that no important features have been hidden.

One problem with the Stereo View tool is that it is very difficult for a human to judge the separation of objects in the foreground and background so as to decide if the rover can fit between two rocks. The Flying Camera tool alleviates this problem by providing a means to examine the in-situ environment from any vantage point. The stereo imagery from the imagers is processed to generate a 3D model of the terrain in the immediate vicinity. This model is stored in a form that can be loaded and visualized with a high level of detail and interactive rendering rates. The camera can then be positioned to view possible routes and constrictions to verify that the rover can indeed traverse the planned route. The Flying Camera tool also supports visualization of a model of the rover that can be positioned anywhere within the environment to verify fit and feasibility.

The Map View tool adds a natural, maplike visualization mode to the suite of tools in the RCW. Consisting primarily of descent imagery, the Map View tool displays the sortie planning area from above at various resolutions depending on the availability of data. It also provides natural access to georeferencing information and to navigation data such as landmark datasets, reference points, and direction. It is easy to lose direction in the Flying Camera tool but the Map View tool displays a compass indicating North when desired. Another indicator points to a specified reference point, such as the lander, to make it easier to navigate samples back to a return vehicle, even when out of sight of the lander. Other features of the Map View tool include specification of hazard or protected regions and contour lines for analysis of slope.

The other main component of the RCW for sortie planning is the Activity Editor which is essentially a text visualization tool for displaying the sequence of commands being produced. All four tools are integrated with a message passing executive which maintains a consistent view of the planned sequence among all the tools. Commands, such as traverse to waypoint, may be specified in any of the tools and the creation or editing of such a command is immediately reflected in the other tools. Additionally, multiple copies of each visualization tool may be launched by the same executive yet running on distributed systems to provide for a collaborative planning environment.

Other tools to be integrated within the RCW include a Telemetry Visualization tool to review the previous period's activities as reported by the rover and a Sortie Rehearsal/Simulation tool to perform dynamic simulations of the planned sorties. Comparison of expected behavior to reported behavior can provide important clues to rover performance.

References:

[1] Wright, J., Hartman, F., and Cooper, B., Immersive Environments for Mission Operations, Beyond Mars Pathfinder, proceedings of SpaceOps '98, Tokyo, Japan, June, 1998..

[2] Ivanov, A., Lorre, J., and Maki, J., Image analysis for robotic exploration of Mars, ibid.

[3] Cooper, B., Driving on the Surface of Mars Using the Rover Control Workstation, , proceedings of SpaceOps '98, Tokyo, Japan, June, 1998..

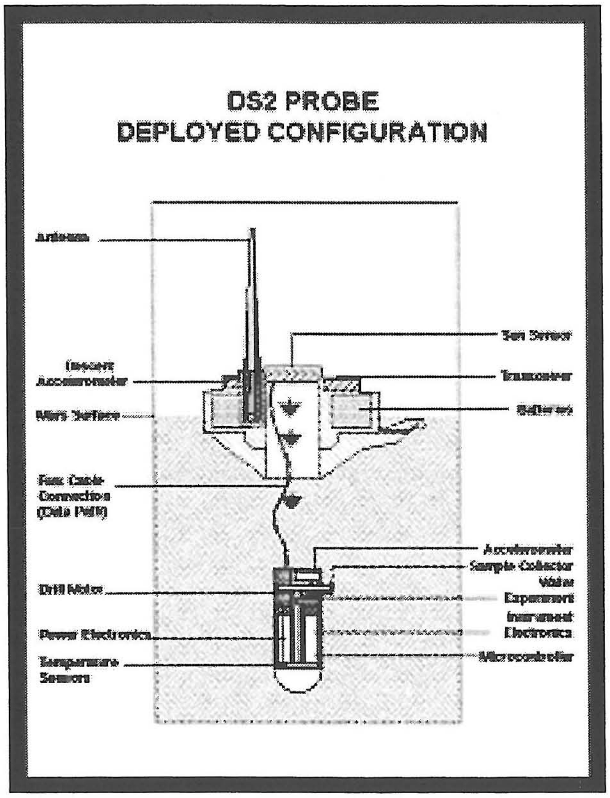
SUBSURFACE SCIENCE FROM A PENETRATOR. A. S. Yen, Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, MS 183-501, Pasadena, CA 91109; Albert.Yen@jpl.nasa.gov).

Introduction ("WHY?"): Much of what we know about the geologic history and present state of Mars is based upon interpretations of data collected from the immediate surface. Unweathered soil samples covered by dust and sand sized particles may provide clues about the role of water and the biological history of the planet. The use of drills and scoops to obtain such samples for lander-based instruments implies the development of relatively large, sophisticated platforms. Small (several kilograms), scientifically focussed penetrators can carry instruments to the subsurface and should be included in the Mars exploration strategy.

Penetrator Platform ("HOW?"): One of the primary objectives of the Deep Space 2 (DS2) Microprobes was to demonstrate the ability to collect and analyze a subsurface sample. Unfortunately, neither of the probes returned data after impact with the martian surface on December 3, 1999. Options for validating the DS2 technologies by retesting aspects of the system are currently being explored. Thus, it is reasonable to expect sufficient testing heritage to conduct a penetrator-based scientific investigation for launch in 2005.

Regardless of the lander or orbiter platforms selected for upcoming launch opportunities, a small penetrator is an ideal piggyback payload and can significantly enhance the scientific return of the mission. The DS2 system consisted of a single stage entry system (~1.2 kg), an aftbody that remained on the surface to provide the telecommunications link (~1.8 kg), a forebody to conduct the subsurface science (~0.7 kg), and the interface hardware to the cruise ring (~2.9 kg). In this design, a subsurface sample is collected by a small drill, sealed by a pyrotechnic actuator, resistively heated, and analyzed for water content by thermal and spectroscopic techniques. An accelerometer was included to provide information on the actual depth of penetration. Thermal conductivity and atmospheric structure measurements were also intended.

Scientific Investigations ("WHAT?"): Here, I present two specific subsurface investigations relevant to water and biology that are compatible with a DS2-like penetrator. These investigation concepts are based upon existing technologies and could be launched as early as 2005 ("WHEN?").



History of water. Images of canyons, valley networks, and outflow channels indicate that liquid water played a significant role in developing the martian geomorphology. However, geochemical evidence in support of a sustained presence of liquid water at the surface is absent. Perhaps the strongest evidence against aqueous weathering of the exposed martian surface is the detection of extensive deposits of unaltered pyroxenes by the MGS thermal emission spectrometer [1]. In a water-rich environment, pyroxene surfaces would be rapidly converted to secondary mineral phases such as clays. Based upon terrestrial weathering rates [2], a 100 micron layer of alteration products would develop on pyroxene surfaces in less than 10^4 years. The apparent absence of clay minerals, carbonates, and hydrated mineral phases challenges the possibility of a "warm and wet" past. Where are the mineralogical markers associated with the putative aqueous history? Is it possible that they are preserved beneath the immediate surface?

A penetrator could provide access to subsurface samples and allow a direct search for indications of past aqueous episodes. The DS2 system provided a method for collecting, heating, and analyzing samples from a depth of approximately 0.5 meters, and minor modifications to this design could be applied to achieve higher temperatures and deeper penetration. Endothermic phase changes and water loss from the soil sample which are diagnostic of hydrated mineral phases can be recorded with temperature sensors and a laser spectrometer similar to DS2. Gypsum, for example, dehydrates at approximately 65 ℃ and 100 ℃, interlayer water can be released from clays between 150 ℃ and 250 ℃, lepidocrocite dehydrates near 300 ℃, goethite evolves water between 350 ℃ and 400 ℃, and certain clays such as nontronite can dehydroxylate at temperatures as low as 450 ℃. Thus, a penetrator with thermal and evolved gas instrumentation could be sent to suspected lacustrine or evaporite units to analyze subsurface samples for the presence of hydrated mineral phases. A positive detection would obviously provide valuable information on the history of water on Mars.

Biocompatibility. The biology experiments onboard the Viking Landers did not detect evidence of life in the soil. In fact, the data revealed an unexpectedly reactive surface environment where organic molecules are actively destroyed by one or more unidentified oxidants in the soil [3]. An understanding of the composition and reactive nature of these chemical species would help guide the search for biological molecules and would allow implementation of appropriate countermeasures for minimizing the risk to humans on Mars. Are these oxidants contained in a shallow (<25 cm) surface layer, or do they extend to depths of multiple meters? How deep do we need to go to have a good chance of finding primitive biomarkers on Mars?

A penetrator providing access to the subsurface would be ideal for determining the vertical extent and variability of the oxidizing species. A sensor technique based on thin-film, metallic chemiresistors is well suited for measuring small changes in oxidizing potential. These chemical sensors are good conductors when unreacted and excellent insulators when oxidized to any of the stable oxides. Thin layers (~100 Å) of metal rapidly exhibit dramatic resistance changes when small fractions of a monolayer of metal are converted to metal oxide [4]. An array of chemiresistors in the forebody sample cup can be compared to a similar set in the aftbody to characterize the reactivity changes with depth. In addition to this gradient information, the rate of oxidation of the different thin-films in the array can provide constraints on the composition of the oxidizing species. Characterizing the vertical distribution and the composition of the reactive component in the soil is essential for understanding the biocompatibility of the surface.

Summary: A variety of scientific investigations including the search for water and unoxidized biomarkers are enabled by access to subsurface samples. A penetrator with minimal resource requirements can be carried to Mars as a piggyback payload to pursue these high-priority questions and can significantly enhance the scientific return of the primary mission.

References: [1] Bandfield, J. L. et al. (2000) *Science, 287,* 1626-1630. [2] Brantley, S. L. and Y. Chen (1995) in *Reviews in Mineralogy (v. 31).* [3] Biemann, K. et al. (1977) *J. Geophys. Res., 82,* 4641-4658. [4] Yen, A. S. (1998) Caltech Ph.D. Thesis.

WATER-SEARCHERS: RECONFIGURABLE AND SELF SUSTAINING ARMY OF SUBSURFACE EXPLORATION ROBOTS SEARCHING FOR WATER/ICE USING MULTIPLE SENSORS. G. U. Youk [1], W. (Red) Whittaker[2], and R. Volpe[3], [1] Inventors' Enterprise, Inc. 1623 Old Fowlkes drive, Brentwood TN 37027, USA (kyouk@servebot.com), [2]Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh PA 15213, USA (red@ri.cmu.edu), [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA (volpe@jpl.nasa.gov)

Objectives: Perhaps the most promising site for extant life on Mars today is where subsurface water has been maintained. Therefore, searching for underground water will provide a good chance to find evidence of life on Mars. The followings are scientific/engineering questions that we want to answer using our approach:

1. Is there subsurface water/ice? How deep it is? How much it is? Is it frozen?
2. What kinds of underground layers exist in Martian crust?
3. What is the density of Martian soil or regolith? Can we dig into? Should we drill into?
4. Can a sudden release of underground water happen if a big asteroid hit the Mars?

Our approach will be able to provide essential information to answer the questions. Moreover, dependent on the water content and depth in soil, not only resultant scientific conclusions but also proper digging/drilling method can be suggested. "How much water in the Martian soil?" There can be several possibilities: large water content that is enough to form permafrost, or small water content that is not enough to form permafrost, or different layers with different moisture contents. "How deep a rover should dig into soil to find water/ice?" The exact size-frequency distribution has not been measured for the soil particles. On-board sensors can provide not only the water content but also the density (or porosity) of Martian soil as a function of depth.

Step-by-Step Approach down to an Army of Remote Sensing Rovers: Finding underground water on a planet like Mars would be much more difficult than finding it under our own desert since there is no rain on Mars. It is unlikely to find underground water by simply touching down a craft on Mars and digging several feet at that location. Instead, step-by-step approaches, starting from remote sensing (several hundred km resolution) using satellites, then aerial searches (less than one km resolution) using airplane, and narrowing it further down with ground searches over the area (less than a couple of m resolution) using rovers as shown in Figure 1, will increase the chance of finding water/ice drastically. Even with rovers, it is almost impractical to drill holes randomly here and there over the wide area of coverage looking for a water/ice signature. It is very time consuming and impractical to drill/core continuously over the wide area to find potentially low fraction of water/ice without an initial aerial survey. Therefore, a step-by-step approach down to rovers to pin point the most probable location to find water/ice is suggested.

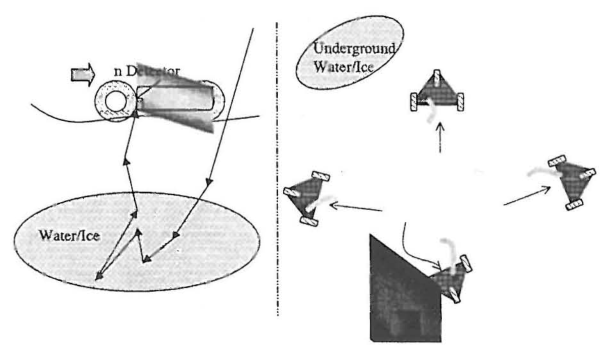


Figure 1. Surface mobile platforms with sensors to survey underground water/ice layers.

Subsurface Direct-Characterization: a Digger: One of the primary purposes of the rover with water sensors is for the initial survey of water/ice tables over the wide area near a landing zone before one set of drilling/coring effort begins. A rover with various sensors will search the area to find water/ice. Once a rover finds a considerable amount of hydrogen, the survey rover will be reconfigured to a digger (the lower part of the survey rover) and a surface (solar power/communication) module (the upper part of the survey rover). The digger, packed with sensors, can go down into subsurface. On Mars or other planets, using a conventional penetrometer has many limitations in penetrating deep into soil due to various constraints. A potential solution can be a self-propelled drill (the digger). The configuration will enable not to drill most rocks but to go around it to save power and to penetrate deep. With sensors housed in the digger, the digger can measure soil moisture contents and soil density at an underground location.

Advantages/Benefits: The idea is unique in that it can search a wide area for water/ice and provide initial survey data –i.e. most probable location to find water/ice -- for penetration/drilling/coring tasks. Due to sensors' high penetrating power to non-hydrogen materials such as dry soil, the suggested approaches are ideal to detect water/ice underneath of a soil layer of the Martian surface. The suggested system can also provide scientifically valuable information such as soil density, subsurface structure, composition, etc. The scientific information about subsurface soil properties and about geological findings will open the new insight into the understanding the geological and climate history of planets and advance the autonomous scientific exploration technology for space science and the human exploration of space drastically.

USE OF VERTICAL LIFT PLANETARY AERIAL VECHICLES FOR THE EXPLORATION OF MARS.

L.A. Young[1] , G.A.Briggs[2], M. R. Derby[3], E.W. Aiken[4],[1]Army/NASA Rotorcraft Division, Mail Stop T12-B, NASA Ames Research Center, Moffett Field, CA 94035 (layoung@mail.arc.nasa.gov), [2]Center for Mars Exploration, NASA Ames Research Center, [3]Aerospace Computing, Inc., Los Altos, CA, [4]Army/NASA Rotorcraft Division, NASA Ames Research Center.

Introduction: Despite the thin, cold, carbon-dioxide-based atmosphere of Mars, recent work at NASA Ames has suggested that vertical lift (based on rotary-wing technology) planetary aerial vehicles could potentially be developed to support Mars exploration missions [1]. The use of robotic vertical lift planetary aerial vehicles (VL PAVs) would greatly augment the science return potential of Mars exploration. Many technical challenges exist in the development of vertical lift vehicles for planetary exploration. It only takes the realization that the world altitude record for a helicopter is less than 40,000 feet (versus flight at the equivalent terrestrial altitude of over 100,000 feet required to match Mars' surface atmospheric density) to appreciate the aeronautical challenges in developing these vehicles. Nonetheless, preliminary work undertaken at NASA Ames and others [2,3] suggest that these vehicles are indeed viable candidates for Mars exploration.

Why vertical lift vehicles for planetary exploration? For the same reason these vehicles are such flexible aerial platforms for terrestrial exploration and transportation: the ability to hover and fly at low-speeds and to take-off and land at unprepared remote sites. Further, autonomous vertical lift planetary aerial vehicles would have the following specific advantages/capabilities for planetary exploration:

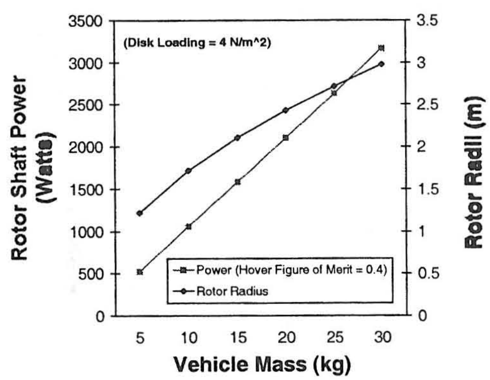
- Hover and low-speed flight capability would enable detailed and panoramic survey of remote site(s);
- Vertical lift configurations would enable remote-site sample return to lander platforms, and/or precision placement of scientific probes;
- Soft landing capability for vehicle reuse (i.e. lander refueling and multiple sorties) and remote-site monitoring;
- Hover/soft landing are good fail-safe 'hold' modes for autonomous operation of planetary aerial vehicles;
- Vertical lift planetary aerial vehicles would provide greater range and speed than a rover while performing detailed surveys;
- Vertical lift planetary aerial vehicles would provide greater resolution of surface details, or observation of atmospheric phenomena, than an orbiter;
- Vertical lift vehicles would provide greater access to hazardous terrain than would be provided solely by lander or rover.
- Could act as 'Astronaut Agents' for efficiently and comprehensively conducting scientific exploration.

Exploration With a Vertical Lift Component

Opportunities & Challenges:.

Opportunities. Robotic Martian rotorcraft are unique compared to other proposed aerial platforms (aerostats and fixed-wing airplanes) for Mars exploration. The very nature of such a vehicle would be its ability to fly close to and interact with the Martian surface. As was once humorously noted, no one is likely to build runways on Mars. Nonetheless, it is the expectation of the authors that an abbreviated sort of 'evolution of flight' will occur on Mars: balloons will likely be flown first, followed by fixed-wing aircraft, and then rotary-wing/vertical-lift vehicles. These various types of aerial platforms will likely be complementary to each other in their ability to meet unique mission requirements and science objectives. Robotic missions using Martian rotorcraft could include aerial survey work, precision placement of small science probes (or micro-rovers) on the planet's surface, or even support sample return missions by acquiring/retrieving small soil samples from remote sites. Martian rotorcraft could also support the human exploration of Mars. Martian autonomous rotorcraft could act as 'astronaut agents' for the future explorers providing them improved 'mobility' -- and safety.

Technical Challenges. Autonomous vertical lift PAVs will be high-risk and high-payoff development ventures. Though an impressive – and ever-expanding -- amount of data exists for Mars, nonetheless, these data are barely adequate for the purposes of designing and building PAVs. Such vehicles will need to be highly adaptive (from a controls and structures perspective), have conservative performance margins, and will require high degrees of mission/flight autonomy to adequately deal with corresponding levels of uncertainty in the mission and flight environment. Martian autonomous rotorcraft by their nature will have large lifting-surfaces and will be required to have ultra-lightweight construction. This in turn will pose a challenge in making them sufficiently robust to operate in the Martian environment.



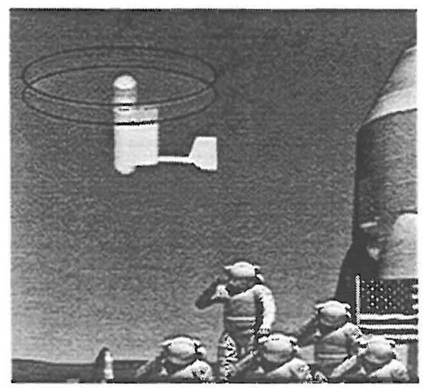
Large, Ultra-lightweight, Fragile…

Early 'Scout' Missions: As noted above, early missions for Martian autonomous rotorcraft will undoubtedly be for aerial survey of the Martian surface. One such aerial scouting mission could focus on mapping a survey area inclusive of the entry error ellipse projected for a follow-up mission.

Two concepts are currently being assessed at NASA Ames for an aerial scout role: an air-deployed autorotating, or partially-powered, 'reelable' rotor design [4,5], and a lander-based, surface-launched, coaxial helicopter design with folding/telescoping rigid blades. Propulsion options include hydrazine 'tip-jets' for the reelable rotor design, and electric motors, or an Akkerman hydrazine reciprocating engine [6], for coaxial helicopter.

Current Status of Work at NASA Ames: Work to date has focussed on conceptual design studies. As a result, reference [1] provided an initial discussion of the technical challenges and opportunities of vertical lift PAVs. In addition to the vehicle studies, a university grant was initiated to develop a conceptual design of a mission/flight control computer architecture for a Martian autonomous rotorcraft. The Year 2000 American Helicopter Society Student Design Competition was initiated focusing on the design topic of a Martian autonomous rotorcraft. Paper design studies from the participating universities have been received and are currently being reviewed by the competition judges. The winning teams of this competition will be announced at the next Annual Forum of the American Helicopter Society.

Ongoing work is focused on the refinement of Ames-generated MARS conceptual designs, as well as initiating development of low-cost proof-of-concept test articles for demonstrating critical MARS technologies – including the development of a hover test stand for testing full-scale rotors at Mars atmospheric densities and a tethered hover flight demonstrator.



Martian Rotorcraft as 'Astronaut Agents'

References:.

[1] Young, L.A. et al. (Jan. 2000) *AHS Vertical Lift Aircraft Design Conference, San Francisco, CA.*

[2] Savu, G. and Trifu, O. (1995) AIAA-95-2644

[3] Gundlach, J.F., "Umanned Solar-Powered Hybrid Airships for Mars Exploration," AIAA 99-0896, 37th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, January 11-14, 1999.

[4] Spangler, S. B. and Nielsen, J. N. (Jan. 1972) AIAA-72-66

[5] Utgoff, V. V. (Aug. 31-Sept. 3, 1982) *Association Aeronautique et Astronautique de France, European Rotorcraft Forum, 8th, Aix-en-Provence, France.*

[6] Akkerman, J.W. "Hydrazine Monopropellent Reciprocating Engine Development" NASA Conference Publication 2081, 13'th Aerospace Mechanisms Conference, Proceedings of a Symposium held at Johnson Space Center, Houston, TX, April 26-27, 1979.